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THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1863-64.

November 10, 1863.

JOHN HAWKSHAW, President,
in the Chair.

No. 1,097.—"Description of Lighthouses lately erected in the Red Sea."[1] By WILLIAM PARKES, M. Inst. C.E.

ON the 30th December, 1859, the Author was instructed by the Board of Trade to proceed to Egypt, for the purpose of making the necessary preliminary surveys and arrangements for establishing lights to facilitate the navigation of the northern portion of the Red Sea.

The Egyptian Government had undertaken to erect the necessary buildings, from designs to be furnished by an Engineer nominated by the English Government; in consideration for which, and for the maintenance of the lights, it was to be permitted to levy passing tolls upon the shipping, a large proportion of which consisted of the mail-steamers belonging to the Peninsular and Oriental Steam Navigation Company. The English Government further undertook to provide the lanterns and light-apparatus, for which a sum of £7,000 had been voted by Parliament.

The opinions of many Commanders in the Peninsular and Oriental service were furnished to the Author, and in the month of February, 1860, he personally visited the greater part of the sites indicated by these officers. The result of his survey was the recommendation that lights should be established on three sites:—
I. Zafarana Point, on the Egyptian shore, 50 miles from Suez.
II. The Ushruffee Reef, on the western side of the navigable channel of the Straits of Jubal, 150 miles from Suez; and,
III. The Dædalus Reef, in the centre of the Red Sea, 350 miles from Suez, and 180 miles from the entrance of the Gulf of Suez. (Plate 1, Fig. 1.)

[1] The discussion upon this Paper occupied portions of two evenings, but an abstract of the whole is given consecutively.

The shores of the Red Sea are, as a rule, fringed with submerged coral reefs, both detached and continuous, which, in many cases, rise abruptly from very deep water; so that soundings give no warning of their neighbourhood. Frequently the sides of the reefs are absolutely vertical from a depth beyond the reach of a ship's ordinary sounding-line. For this reason the Commanders endeavour to keep a course as near the centre of the sea as possible, so as to give a wide berth to these hidden dangers. Previous to the establishment of the lights, the landmarks for navigation consisted of a series of bold headlands and high islands, which are almost always visible at night in the clear atmosphere of that climate. The principle was therefore adopted of placing the lights on intermediate points, where the continuity of the series of landmarks was broken; thus converting what had hitherto been dangers, into elements of safety.

Zafarana Point is situated near a turning-point in the navigation; and the appearance of the shores being in that neighbourhood somewhat confused, especially in uncertain lights, frequent instances have occurred of steamers being too near to one shore, or the other, and even of getting aground. The light forms a well-marked object, which gives the position of the ship to a certainty. It was not considered necessary to fix it close to the navigable channel, which is from 2 to 3 miles from the shore: it has therefore been placed on the most projecting point of the mainland.

Passing to the Straits of Jubal—the most intricate part of the navigation of the Red Sea,—the distance from the main shore on one side to that on the other is from 25 to 35 miles, but the outlying islands and reefs reduce the navigable width to 6 miles. The length of what may properly be called the Straits is about 35 miles, and is well marked by the high land of Zeitee at the northern end, and by the high bold island of Shadwan at the southern end, both of which nearly approach the deep water. Between these two points, however, lies the formerly dangerous reef of Ushruffee, to avoid which there was no guide whatever; while abreast of it, on the opposite side of the navigable channel, at a distance of 6 miles, lies the equally dangerous and treacherous Shab Ally Reef. By means of a light on Ushruffee, which is visible from a ship abreast of Zeitee on the north, or Shadwan on the south, a line of navigation is marked off, which leads clear of all dangers.

The Dædalus Reef lies in the direct line of navigation up and down the sea. Unmarked, it was a danger, to avoid which the whole course had to be diverted 20 miles to the westward, and so much the nearer to the dangers outlying from the shore. Marked as it is at present, it becomes a guide to a course which leads clear of all dangers for hundreds of miles.

These three sites, and the general designs submitted by the Author for constructing lighthouses upon them, having been approved by the Egyptian Government, by the Board of Trade, and by the Directors of the Peninsular and Oriental Company, the immediate execution of the works was authorised.

Zafarana Point is on the mainland; and though the country is a desert, with a very limited and distant supply of fresh water, yet as it is within easy reach of Suez, either by native sailing craft, or by camel, it was considered most advantageous to construct a tower and light-keepers' dwellings of an ordinary character, of rubble-stone, and to employ native labour entirely. The general dimensions and requirements of a tower 60 feet high were, therefore, furnished by the Author to the Public Works Department of the Egyptian Government, which is under the direction of H.E. Linant Bey, and the works were carried out by that department in a satisfactory manner. The design presents nothing worthy of special remark, except the peculiar mode of forming the gallery at the top and fixing the lantern. This is ordinarily done by a course of ashlar stone, forming a cornice to the tower, and a gallery round the outside of the lantern; but in remote places, the operation of preparing and setting this course is often troublesome, involving, for one course of masonry, a special material, superior workmanship of a kind which probably is not required for any other part of the work, and much labour in levelling the bed for the lantern, sinking bolt-holes, mortices, &c. In this case, the Author substituted a cast-iron gallery, formed of a circle of boxes of convenient size, which lie upon the rubble masonry, having flanges upon them, to which the lantern is bolted. A gallery of this description can be fixed in a short time by the mechanic who is to erect the lantern, the operation coming within the scope of an ordinary fitter's duties; and the surface of the gallery is afterwards formed by filling the boxes with concrete. The standards for the handrail rest upon the castings, and are firmly bedded in the concrete, without the tedious operation of cutting mortices in hard stone. The lantern has some special arrangements similar to those for the other two lights, which will be described hereafter. The light is a dioptric fixed one of the first order, visible over five-eighths of the circle. Its height above the mean (half-tide) level of the sea is 83 feet, and it is brilliant at the extreme distance at which it dips below the horizon, when viewed from the deck of a ship, or about 14 miles. It was first exhibited on the 1st January, 1862.

The other two sites, the Ushruffee and the Dædalus, present peculiar features, to which the designs for the buildings had to be adapted. As these features are more marked in the Dædalus than in the Ushruffee, it will be desirable to describe the former first.

It has been already stated, that the Dædalus Reef lies nearly in the middle of the sea. It is, in fact, about 45 miles from the western, and 60 miles from the eastern shore. It may be described as a submerged island, with a flat top of an oval form, 1,200 yards in length from N.W. to S.E., and 450 yards in breadth. Its sides are vertical, or even overhanging, so that a common ship's lead-line may be dropped from the edge of the reef without finding bottom. Captain Moresby's chart of 1833 gives no bottom at 150 and 250 fathoms. The nearest deep-sea soundings, taken by Captain Pullen in 1858, give between 700 and 800 fathoms, and those nearer the reef, (the nearest being at a distance of about 10 miles,) are deeper than those further off. The actual surface of the coral is about 6 inches under low water, but there is a small shifting bank of sand near the S.E. end, which is dry at low water, and sometimes also, to a small extent, at high water. The range of tide is about 2 feet at springs.

It is difficult to convey an idea of the structure of a coral reef by any description, though in some of its general features it is obvious enough to the sight. Every one is familiar with the general nature of the specimens of branching coral to be seen in public and private museums. These, however, are not usually fair samples, as the most beautiful and delicate would hardly bear to be removed from their ocean home. The coral reefs of the Red Sea are formed of an accumulation of such growths, at least from a considerable depth. As the insects die, a calcareous deposit appears to take place upon the coral, and this becomes the foundation of a new growth. Several such new growths, interlacing with one another, and with the previous ones, form a kind of network, or skeleton, which ultimately attains the level of the lowest water. At this level the direction of growth is lateral rather than vertical, so that, ultimately, the various branches meet and form a more, or less complete platform a few inches under low water. This surface material is exceedingly hard, and will turn the edge of an iron bar. It sometimes spreads so far laterally, as to overhang, by upwards of 1 foot, the stem which carries it; and there are places where, within about 10 feet of the extreme edge of the Dædalus Reef, small apertures occur in the natural surface platform, through which the blue unfathomable water may be seen below.

It is only in some cases, however, that the surfaces of coral reefs arrive at this stage: more frequently, before the top surface is formed into a continuous platform, portions of the branching coral most exposed to the waves will have been broken off, and, being driven about by the sea, be reduced to sand. This sand, settling in the cavities of the reef, prevents additional growth from the parts which are covered by it; and then the surface platform

remains imperfect, consisting of detached tables of the incrusted coral, separated by pits, in the bottom of which sand lies to the depth of a few inches.

The Dædalus is an instance of a growth thus interfered with by sand, especially near the centre. The Ushruffee, on the other hand, has a small portion near the centre of the reef which is completely crusted over, and the outer portions appear to be in progress towards the same state; the peculiar form of the reef breaking the force of the waves in such a manner as to prevent the formation of much sand, or débris.

Such then were the general features of the sites to which the proposed constructions had to be adapted. The peculiar conditions which had to be considered were mainly the following:—

1. The force of the sea would be completely broken at some distance within the edge of the reef, so that the waves would not fall with any great violence upon the bases of the structures.

2. The structures would have to be built upon the surface of the reef, and not sunk into it, as no additional solidity could be thus obtained, and the advantage of the natural platform at the surface would be lost.

3. In the absence of any definite experience as to the actua weight which the reefs would bear without being crushed, it was desirable to reduce the weight per superficial foot of foundation as low as possible.

4. Taking, for the present, the case of the Dædalus only, all the materials (with one exception to be hereafter named) would have to be brought by ship from Suez, a distance of 350 miles. There being no anchorage, it was necessary that the ship should be a steamer, capable of keeping close to the reef in any wind, and providing quarters for the workmen, and storage room for the materials, until a proper depôt and habitation could be formed on the reef itself. To fulfil these requirements, it was desirable that the materials should be small in bulk, and that the mode of putting them together should be as simple as possible. Moreover, as the whole would have to be carried from the ship to the lighthouses, in boats of such light draught as to pass over the reef, the several portions were required to be light and easily handled.

5. The buildings had to be so designed as to mitigate the intense summer heat.

It appeared to the Author, that the foregoing conditions would be best fulfilled by adopting a structure of wrought iron supported on piles; the piles themselves resting on a bed of concrete, so as to distribute the weight over a fair proportion of area, and the upper surface of the concrete serving as a convenient dry platform, a little above high-water level. The conditions of portability and rapid erection were met by the adoption of a simple

framework, filled in with strong corrugated iron; and the object of mitigating the heat was hoped to be attained, by arranging the building so as to form a series of rooms one above the other, as a central column, with verandahs, or galleries round each room, which, being only partially enclosed by similar corrugated iron panelling, would admit the air, but prevent a portion, at least, of the sun's rays from falling on the walls of the interior room. The sun might be entirely excluded by hanging up canvas curtains at pleasure, so as to close the openings on the sunny side of the building.

In the case of the Dædalus, there was no necessity for fixing the light at any great height. There are no dangers in the neighbourhood, and if seen at a distance equal to the possible error in the course during a day's, or two days' run, it would answer the double purpose of a leading light and a guard from the danger on which it was to be placed. The height was therefore regulated by the necessities of the establishment, and four tiers of rooms, each 9 feet in height, and other necessary arrangements, brought the light to an elevation of 62 feet above the mean level of the sea. Such were the general features of the design for the Dædalus Lighthouse.

In the case of the Ushruffee, the conditions were similar, though less marked. There is anchorage for temporary purposes in from 14 to 20 fathoms all round the reef; there is sheltered anchorage in more than one place in the immediate neighbourhood; and there are several barren islands, within 2 or 3 miles of the reef, on which depôts for materials could be formed, or where, if necessary, temporary quarters could be erected for the workmen. These conditions allowed greater latitude in the design for this lighthouse; but it was considered advisable to adopt the same general form of construction as for the Dædalus. There is, however, this difference in the requirements of the two sites: while the Dædalus Light, as before mentioned, has only to guard the danger on which it is itself placed, the Ushruffee Light has to lead vessels past dangers 12 or 14 miles distant, and consequently a more powerful light, at a greater elevation, was required. The height fixed upon was 126 feet above the mean level of the sea; and in order to obtain this height, the same description of framework as in the Dædalus was carried up for eleven instead of for four tiers. As only the same accommodation (four rooms) was required, seven tiers were designed to be left in skeleton.

In describing the details of the structures, the Ushruffee, as the larger one, will be taken as the type, for it contains all the main features of the Dædalus. Commencing at the foundation, the material for the piles was a matter for consideration. The choice seemed to lie between cast-iron pipes and timber, and the former

was at first sight the more natural alternative. Cast iron, however, is of uncertain durability in sea-water, and the conditions of its greater, or less durability do not appear to be understood. It therefore did not seem to offer any sufficient superiority in this respect over teak of the best quality, to counterbalance certain practical advantages in the employment of the latter. These were principally: 1st, less cost by about one-third; 2nd, less weight by one-half for the men to handle when working up to their waists in water; 3rd, buoyancy in the water, thus facilitating discharge from the ship, and moving from place to place at the work; 4th, facility for accurate adjustment after being fixed in place. Teak was therefore chosen for the piles, with an arrangement by which any pile can be removed, and a new one inserted, without disturbing the superstructure. The piles are 18 feet long and 18 inches diameter: they are arranged in two concentric circles, the inner one 15 feet diameter, consisting of six piles, the outer one of six pairs of piles, the piles of each pair being 6 feet apart. (Plate I., Figs. 3 and 4.) This outer circle is 39 feet diameter at the heads of the piles, and the feet spread outwards at a batter of 1 in 12. The piles stand with their feet upon the surface of the reef, but for the height of 4 feet from the bottom they are flattened on each side, the flattened part terminating in a shoulder, under which, on each side, is placed a sleeper of teak. The whole area of a circle around the piles, 47 feet diameter, is filled to a height of 5 feet with concrete, which is rammed under the sleepers, so as to relieve the feet of the piles from the superincumbent weight. The concrete is enclosed by a caisson of boiler plates, $\frac{3}{8}$ths of an inch thick, set on edge, and bolted and riveted together. The heads of the piles pass through circular wrought-iron collars 18 inches deep, to which they are accurately fitted, and any loosening, by the shrinking of the timber, is provided for, by fitting a number of wedges of greenheart wood, (Plate I., Figs. 11 and 12,) into corresponding grooves in the pile-heads, in which they can be driven down when slack. A direct bearing surface is also given, by iron screws 2 inches diameter, which pass through each collar, and enter 2 inches into the wood. The collars have projecting arms, which are riveted to a system of framing, the nature of which, as well as the principle of the superstructure, will be sufficiently obvious from an inspection of the details given in Plate I. There are two raking piles which were introduced with the view of checking any possible tendency to a rotatory motion in the structure.

The framework of the superstructure consists of a repetition of three main parts, which may be called respectively standards, cills, and radiators. Each tier consists of twenty-four standards, twelve in each circle, connected at the top and bottom by cills, forming two concentric twelve-sided polygons, and the

corresponding angles of the polygons are connected by the radiators. The standards, (Plate I., Figs. 14, 15, and 16,) are in lengths of 9 feet, and consist of a web plate and two angle irons riveted on to it. The web plates are $8\frac{1}{2}$ inches $\times$ $\frac{1}{2}$ inch for the lower tiers; 7 inches $\times$ $\frac{1}{2}$ inch for the middle tiers; and $5\frac{1}{2}$ inches $\times$ $\frac{1}{2}$ inch for the upper tiers. The angle irons are of proportional sizes. The angle irons project at the top and bottom beyond the web plate, so that when one standard stands upon another, there is a space left between the angle irons through which the end of the radiator passes. Joint-plates on each side of the web are riveted to the head of one standard, the foot of another, and the radiator between, forming a very stiff connection for the whole. (Plate I. Fig. 13.) Where there are no floors, the radiators consist of plates $\frac{1}{2}$ an inch thick, and $7\frac{1}{2}$, $6\frac{1}{2}$, and $5\frac{1}{2}$ inches deep, at different heights. Where there are floors, angle irons are riveted on to the top and bottom of the radiators, which then serve as girders. The cills are riveted to the angle irons of the standards, and to one another, through the joint plates and webs of the standards, by means of small knees of angle iron. This system of framing was carried up to the top.

With the exception of a few of the parts near the bottom, no separate piece exceeds in weight about 4 cwt.; so that the whole could be lifted by quick-acting tackle, and be easily carried about from place to place by two, or three strong men. It may also be observed, that with the exception of the angle irons of the standards, which had to be opened out from the square to the bevil of the angle of the polygon, none of the main parts had to be heated for fitting, all the joints being formed with straight-cut ends.

The floors, of which there are five, consist of cast-iron plates $\frac{1}{2}$ an inch thick, resting upon the lower flanges of the cills, and covered with 6 inches of concrete. Additional support is given to each of the floors, except the lowest, by two wrought-iron beams, riveted to the standards under them. From the lowest floor is suspended a hemispherical water-tank, which gives the requisite support. This tank is capable of holding about 1,500 gallons of water.

The floors of the galleries are formed of open cast-iron gratings, which rest on the cills and radiators. These permit a free current of air to circulate vertically. The sides of the rooms are formed of corrugated iron $\frac{1}{8}$th of an inch thick, riveted to the standards and cills. The distance between the outer and inner circles of standards near the bottom being unnecessarily great for the width of the galleries, an intermediate circle is inserted, consisting of T-iron standards and cills, similar in form to the main cills but lighter. The spaces which occupy the short sides of the polygon are completely filled in with corrugated iron; and those which

occupy the long sides, to a height of 4 feet from the gratings, the top being finished by a hand-rail of teak.

The upper of the three rooms at the lower part of the building is covered with two wrought-iron roofs, the lower one covering the inner room only, and the outer one, which is placed about a foot higher, covering the galleries also. Each has an aperture in the top, covered by a detached cone.

The sides of the watch-room, at the upper part of the building, are enclosed in a similar manner to those of the rooms below, except that the gallery occupies the whole space between the inner and the outer circles. The inner circle is carried up 7 feet above the top of the watch-room, and is fitted with the usual details of a lantern pedestal, with some modifications which will be described in connection with the lantern. The two circles are connected by a ring of cast-iron plates, forming a gallery round the pedestal of the lantern. This gallery is furnished with a projecting cornice of cast-iron plates bolted on to the top cill of the outer circle, and the space between it and the sides of the lantern pedestal is filled in with concrete. A railing is carried round the gallery, supported on cast-iron posts, bedded in the concrete.

This system of framing is perhaps as strong as any that can be made with parts exclusively vertical, or nearly so, and horizontal. In those portions of the structure which are enclosed by corrugated iron, the required addition of diagonal strength is fully given; but in the skeleton parts, this was specially provided for in the manner to be hereafter described. The only considerable force which this building has to withstand is that of the wind. The Red Sea is never visited by the hurricanes which are frequent in many tropical regions, and are even occasionally felt on the shores of Great Britain. There are no trustworthy data as to the greatest force of wind to be expected; but by the general evidence of seafaring men, acquainted with the locality, such gales as those which, in this country, are registered as giving a pressure of 20 lbs. to 25 lbs. on the square foot, are probably unknown. In the absence, however, of positive data, it was considered advisable to keep in mind the possibility of a pressure of 50 lbs. on the square foot.

To compare the force of the wind with the theoretical elements of strength in the structure would be an interesting investigation, but it is one involving many difficult points in mathematics, which the Author thinks would scarcely be appropriate in a Paper descriptive of an executed work; he therefore confines himself to the general objects of the design, and a description of the tests to which the structure has been subjected.

The action of the wind with which it appeared most difficult to

cope was the possible establishment of a twisting, or rotating motion in the whole structure, which, if once started, might be maintained, and even aggravated, by the inertia of so great a weight of materials. To meet this possible action, diagonal crosses of round rods were introduced into the spaces forming the short sides of the polygon. Their necessity was soon felt, as when the building had been raised six tiers without them, in the yard of Messrs. George Forrester and Co., the contractors at Liverpool, it was found to be so shaky, that the workmen were unwilling to go upon it. The diagonal braces were then put in up to that height, which made the erection perfectly steady, and they were continued to the full height without any further sign of weakness.

While at its full height, with the exception of the piles at the bottom and the lantern at the top, and with the joints merely bolted together, it was exposed, in September and October, 1860, to two gales of wind of the registered force respectively of 20·5 lbs. and 24·3 lbs. on the square foot. There was no evidence of any straining of the joints under these severe tests, and while the wind was still strong, though not at its greatest force, a careful examination failed to discover any oscillation at the top, though there was a sensible vibration. After it was erected on the reef, in June, 1862, a gale of wind, said by the Arabs of the neighbourhood to have been more than ordinarily severe, had a similar effect. Mr. Scott, the Resident Engineer, who had experienced the effect of heavy gales on two cast-iron plate lighthouses in the West Indies, was of opinion that the vibration was rather greater than in those structures, though not materially so. The report of the lightkeepers as to the effect of another heavy gale, in January, 1863, was that the top of the building vibrated considerably; but a subsequent examination, by Captain Kirton, showed no symptoms of straining having taken place. At no time has any rotatory movement been detected as caused by the wind. From these tests, it might be fairly concluded, that the rectangular framing, aided by the diagonal bracing in the short sides of the outer polygon, was sufficiently stiff for the purpose, no sign of weakness having betrayed itself in any part. It was, nevertheless, considered desirable, as an additional precaution, to give a more complete attachment between the inner and outer circles. With this view, two tiers of radiating diagonals were introduced, as shown in Plate I., Fig. 3. They consist of rods $1\frac{1}{4}$ inch diameter passing from the upper ends of the outer standards to the radiators immediately in front of the feet of the corresponding inner standards.

The general principles of the construction of the Dædalus Lighthouse are the same as those of the Ushruffee, with such modifications as its smaller size demands. There are only twelve instead of eighteen piles, and these are bedded in a block of concrete 36

feet diameter and 4 feet deep, instead of 47 feet diameter and 5 feet deep. The dimensions of the parts of the framework are the same as for the upper tiers of the Ushruffee. The rooms are of the same size as in the Ushruffee, but the lantern being smaller, arrangements had to be made for reducing the diameter of the polygon above the watch-room. This is done by placing upon the watch-room standards a circle of cast-iron coved plates, as shown in Plate I., Fig. 8. The floors of the rooms, and the open gratings of the galleries, are the same as in the Ushruffee. The building is stated to be very rigid, scarcely any vibration being perceptible under a strong breeze.

The lanterns are of the same construction for the three light-houses. Those for the Ushruffee and the Zafarana, being for first-order lights, are the same in every respect. That for the Dædalus being for a second-order light, is of reduced size. In construction they are similar to those generally manufactured for the Trinity Corporation; but there are some special arrangements for mitigating the powerful effects of the sun. With this view the cills which connect the tops of the standards are made deeper than usual, and with apertures in the faces to admit the air. A roof of the ordinary construction, consisting of radiating gun-metal rafters covered with sheet copper, springs from the upper side of the cill. It has an opening at the apex covered by a detached cone. This roof is lined on the under side with deal boarding. From the lower part of the cill springs a light wrought-iron roof, having a circular aperture in the centre, which can be closed at pleasure by a disc, fixed on the end of a moveable tube, which passes up to the apex of the outer roof. When the aperture in the inner roof is closed, the whole current of air through the lantern passes through the centre of the roof into the wind-guard on the top, as in the usual arrangement; and this is ordinarily the case at night when the lamp is lighted; but in the daytime, when the sun is acting powerfully on the external roof, and the air between the two roofs is heated and rarified, the disc may be lowered, and an additional current be established from the lantern. The second roof has the further advantage of preventing radiation from the heated upper roof into the interior of the lantern. This arrangement is said to answer satisfactorily, and to be of advantage in keeping down the temperature of the lantern. The wind-guard on the top was substituted for the ordinary revolving vane and cowl at the suggestion of Professor Faraday. It is in principle the same as those now frequently placed at the tops of flues, and has the property of causing an upward draught, whatever be the direction of the wind. It has been successful in situations where the revolving cowl has failed.

With the view of giving a greater area than usual for the admis-

sion of air to the lower part of the lantern, ventilators of a peculiar form were introduced; but they do not appear to be of so much advantage as was anticipated, and probably there is nothing better for this purpose than the ordinary hit-and-miss turn-plate.

The door leading from the light-room to the outer gallery is generally made to open outwards, which is inconvenient when it is blowing hard. In these lighthouses the door is made to slide, one half of one of the wide panels running on rollers behind the other half. Some careful workmanship is required to make the door air-tight when closed; but, on the whole, it is believed to be an improvement on the ordinary practice.

The lanterns and light apparatus for the three lighthouses were furnished by Messrs. Wilkins and Co.; Messrs. Chance, Brothers, having manufactured the optical portion. Zafarana is a fixed light of the first order; Ushruffee, a revolving one of the first order; and the Dædalus, a fixed one of the second order. The lenticular apparatus was manufactured and adjusted in a beautiful manner by Messrs. Chance. The improvements which they have introduced into this manufacture deserve, however, a more special notice than would be compatible with a casual introduction of the subject of lighthouse illumination in the present communication.

The whole of the materials of the two iron lighthouses, and the three lanterns and light apparatus were, with some few exceptions, despatched from Liverpool on the 28th October, 1860, and arrived at Alexandria on the 12th November following.

As comparisons have sometimes been made between the time required for the prosecution of undertakings under Government, and of those under private direction, to the disadvantage of the former, the progress made in this undertaking may be cited as a favourable instance of official energy. Within ten months from the date of the Author receiving his instructions, the sites were surveyed at a distance of nearly 3,000 miles from home: the sites and designs were approved by the Egyptian Government, the British Government, and the Peninsular and Oriental Company; contracts were entered into, drawings and specifications prepared, and the materials for two lighthouse towers and three lanterns and light apparatus manufactured, erected, taken down, and despatched to their destination.

As the structures were designed with a special view to the peculiar circumstances of the sites upon which they were to be erected, it will be desirable to give some account of the operation.

The Peninsular and Oriental Company had undertaken to give, gratuitously, the services of the 'Union,' a screw-steamer of 300 tons and 60 H.P., the Egyptian Government to be at the charge of all wages, stores and coal. She was considered

small for the purpose, and proved to be so, but no other ship was available. She was manned by Lascars, with about six European seamen, under officers in the Company's service.

The general arrangements made were the following:—

The lighthouse on the Ushruffee Reef was to be undertaken first, because it was considered that any omissions in the arrangements could be more easily rectified there than at the Dædalus, both from the fact of its being so much nearer Suez, and from the neighbouring islands affording opportunities for forming depôts for materials, coals, &c., or even for temporary quarters for workmen if required. It was thought that the experience gained in this work would diminish the risk of omissions in the preparations for the more distant operations at the Dædalus. Two leading mechanics were recommended by Messrs. Forrester and Co., the constructors of the towers, and two by Messrs. Wilkins and Co., the constructors of the lanterns and apparatus. The subordinate workmen, consisting of two riveters and two labourers, were attached to the ship, so as to be under the direct orders of the officers; and two of the ship's engineers were especially appointed to assist, under the general superintendent, in carrying out the works. Unskilled labour in hoisting, &c., was to be drafted from the ship's crew as required.

The concrete was arranged to be prepared by the Public Works Department of the Egyptian Government, the officers in which service had had considerable experience in that material. It was to be made in the mode more practised abroad than in this country. Lime and pozzuolana, (the latter from the island of Santorini off the coast of Greece,) are mixed in proper proportions to form mortar. Then the mortar is mixed with a proper proportion of broken stone, and the whole allowed to stand for some days before being placed in the water. It is slow setting, but after some months it becomes very hard. The practice of allowing the concrete to remain for some days before being deposited seemed considerably to facilitate the operation; for if it could be made at Suez, and be then put on board the vessels which were to convey it to its destination, the time of the voyage would be occupied in the required delay, and on arrival at Ushruffee, no further labour would be necessary than the simple transport of the material from the vessels to the lighthouse. The prevalence of a favourable northerly wind reduced the risk of delay in the voyage; and it was estimated that even a considerable loss of material from premature setting would be compensated for, by the greater facility of this process over that of preparing it on the spot. It was found by experiment, that the setting properties of the lime were not materially damaged seven days after mixing; and, although there was no opportunity of carrying that experiment further, the native

foreman supplied by the Egyptian Government was confident from his experience of the materials, that it might be extended to fifteen or even twenty days. It was supposed that three or four days would ordinarily be sufficient to bring a cargo from Suez and deposit it at the lighthouse; and the whole quantity of 500 tons was arranged to be sent in five detachments, succeeding one another. It will presently be seen how this arrangement worked.

The materials from England, as has been before stated, arrived at Alexandria on the 12th November. It could hardly have been anticipated that much time would be required in transporting between 300 tons and 400 tons of such materials by railway to Suez, but the necessities of Eastern routine required four weeks for this operation, and it was not till the 20th December that the materials of the Ushruffee lighthouse were placed on board the 'Union,' and those for the Dædalus lighthouse on board the Peninsular and Oriental Company's store-ship 'Precursor,' lying in Suez Roads. During this time, however, three flat-bottomed boats, capable of carrying about 5 tons each over the reefs, which had been sent out in pieces by Messrs. Forrester and Co., were put together.

On the night of the 20th December, 1860, the 'Union' started upon her expedition. The Author accompanied her with the hope of seeing a commencement made, and it was arranged that the first cargo of concrete should be despatched from Suez on the 28th. This, allowing for the quicker voyage of the steamer, would give about ten days for making ready for the concrete upon the reef. Unfortunately, however, for some days after the arrival at the Ushruffee, a continuance of high winds caused a difficulty in getting materials to the spot, especially with the then imperfect knowledge of the best approaches. This delay prevented anything being done till the 2nd of January, 1861, when the Author was obliged to leave; but there was then every prospect of a successful commencement, and though the sacrifice of some portion of the concrete seemed probable, that had been anticipated as a possibility. These hopes, however, were not destined to be fulfilled. The erection of the piles which had been expected to be a short and simple operation,[1] turned out to be in this case a tedious one, and after four weeks' labour was still incomplete. At the end of this time, the concrete had set hard in the vessels, and was useless, and the whole undertaking had for a time to come to a standstill. It was impossible without delay to obtain materials for new concrete, and such delay would have thrown the work into the hot season, when it must have been suspended. The superintendent, therefore, acted

[1] The corresponding operation at the Dædalus occupied eight days, including one Sunday when no work was done.—W. P.

to the best of his judgment in making dispositions for the renewal of the work in the following season. His experience led him to think, that the work would be better carried on by forming a complete land establishment on one of the neighbouring islands, $1\frac{1}{2}$ mile distant from the reef, and carrying out the men and materials daily by boat, without the constant attendance of a steamer. He therefore landed all the materials upon this island, put them under the charge of a responsible Government official from the neighbouring village of Tor on the opposite side of the gulf, and broke up the expedition.

It is not unnatural that those who had taken a responsible part in this unsuccessful expedition should have exaggerated the future difficulties of the work, and it is equally natural that those who heard their reports should go one step further and consider the undertaking a total failure. The matter was still further complicated by the prevalence of a fear, since proved to be groundless, of the insecurity of the foundation.

From a careful consideration, however, of all the alleged facts, the Author felt that he could not concur in this gloomy view of the undertaking. An attempt had been made, perhaps with too much confidence, to adjust the successive steps of the operation so that no time might be lost, and if it had succeeded, then the Ushruffee light might have been exhibited, as was proved to be practicable by subsequent experience, before the summer of 1861. Such modifications in the plans, as would have avoided the possibility of failure, would have, at the same time, prevented the possibility of saving the season.

Such then, when cleared of its surrounding mystifications and unfounded fears, appeared to the Author to be the full extent of the failure. The authorities of the Board of Trade took the same view, and lent the weight of their authority to lead the Egyptian Government and the Peninsular and Oriental Company to renew the attempt in the following cool season. In this both acquiesced, and the Author was instructed to make arrangements for a new expedition. Under the peculiar circumstances he readily agreed to the suggestion of the Board of Trade, that he should himself remain on the spot till the operations, as to which difficulty had been anticipated, were completed.

The permanent superintendence, however, was placed in the hands of the late Mr. Charles William Scott (Assoc. Inst. C.E.), and the command of the 'Union,' which had been sent to Bombay for repairs, and was now ordered back to Suez, was confided to Captain William Kirton, of the Peninsular and Oriental Company's service.

The altered circumstances of the case demanded modifications in the original arrangements. The materials having been landed

on the Ushruffee island, turned the balance in favour of making a land establishment for the working party there, rather than of quartering them on board the steamer, which would thus be at liberty to carry the Author and a working party to the Dædalus, without interfering with the operations at the Ushruffee under Mr. Scott.

The arrangements for the concrete were also changed. Though the cause of the failure of the first concrete is now clear enough, it was then mystified with so many suppositions and misunderstandings, that two conditions seemed necessary: 1st, that there should be no possibility of even partial failure; and, 2nd, that the arrangements should not be complicated by any partial responsibility on the part of the Egyptian Department of Public Works. The Author, therefore, determined on sending out Portland cement for that portion which would have to be deposited in the water; while the upper portion might be formed of the local concrete, about the success of which, in such a situation, there could be no doubt.

It was also decided that the 'Union' should be entirely manned by Europeans, the Lascars on the former expedition having made difficulties about giving their services at the lighthouse works. The mechanics and other civil workmen, in all twelve men, were to be placed directly under Mr. Scott, with liberal wages and special stringent agreements, instead of being borne on the ships' books as before. Mr. Scott was to have also a picked European boat's crew of six men for the island establishment, but borne on the books of the 'Union.' Dr. O'Neill, of the Company's service, was to act as surgeon and purser of the establishment. As more boating would be required than was originally contemplated, owing to the distance of the island from the reef, (a mile and a half,) two additional iron lighters were furnished by Messrs. Forrester and Co.; and two small sea-water distilling apparatus, which were to be afterwards placed in the lighthouses, were supplied by Dr. Normandy and Co. The list of plant and materials was also generally revised, and the losses on the first expedition made good: and 100 tons of Portland cement were sent out by Messrs. White, Brothers.

The staff being thus organised, and the materials having arrived in Egypt in September and October, 1861, two events concurred to prevent a favourable commencement of operations. The 'Union,' which had left Bombay before the termination of the south-west monsoon, being a vessel of small power, was unable to make head against it, and did not arrive at Suez till the 26th October. During the same month a breach occurred in the railway between Alexandria and Cairo, and communication between the two places was much retarded, notwithstanding the extraordinary exertions made by the late Viceroy and his transit administration to provide other means of transport. Owing to these

causes, it was not until the 6th November, nearly a month later than had been expected, that the 'Union' was ready for sea.

During the interval, however, the native workmen and materials required from the Egyptian Government were collected, including a supply of gravel suitable for the Portland cement concrete, which was obtained from the line of the railway in the desert, about 30 miles from Suez. This was to be sent down by sailing vessels immediately after the departure of the 'Union.'

On the 8th November, 1861, then, operations were resumed at the Ushruffee. The first step was to form the shore establishment for the accommodation of the staff, both European and Arab. The number of the latter was about fifty, including carpenters for the erection of huts for the Europeans, and labourers for the deposit of the concrete and removal of materials. As their stay would not be long, they were lodged in tents. Four wooden huts were erected for the Europeans. The condensers were placed upon a stage over a shallow bay, from which water could be easily drawn, and the two additional lighters were put together. It was essential that these operations should be completed, and all the necessities of the future inhabitants be provided for, before the steamer could leave. Owing to the inconceivable want of skill of the native carpenters, it occupied three weeks to get the huts ready for occupation.

During this time some progress was made at the lighthouse works. The caisson of iron plates to enclose the concrete base had been set up, and about 200 tons of gravel had been deposited upon the reef, where it was exposed to a wash sufficient to remove some of its clayey particles, without carrying it out of reach. As soon as a sufficient quantity of gravel was accumulated, the process of depositing the concrete was commenced. As circumstances did not admit of the usual plan of depositing the concrete in the water in large masses, from boxes, the following plan was substituted :— Sheets of tarred canvas were prepared of such sizes as would fill up the spaces between the piles and allow 2 feet round each side to be turned up, so as to form large shallow bags. The edges of the tarpaulin were then lashed to wooden rods which were slung to the piles so as to allow the tarpaulin bag to float slackly on the surface of the water. Two or three hours before low water the work was commenced. The concrete was mixed in the lighters moored alongside the caisson, six measures of gravel being used with one measure of cement and a suitable quantity of water. The materials were thrown into the centre of the canvas bag, which gradually sank to the bottom, (generally from 1 foot to 2 feet under water), and the bag was spread out evenly over the whole area as it became filled. This was continued until the tide rose nearly to the level of the top of the deposited

concrete, when the sides of the tarpaulin were drawn close down over the soft mass and lashed tight. In this way blocks of from 6 tons to 14 tons were deposited without the material having been subjected in small quantities to the action of the water. The blocks were generally hard enough on the following day to allow of the exposed parts of the tarpaulin being cut away, and so complete was the set, that the casts of the cords and the edges of the tarpaulin were often sharply impressed upon the face of the concrete.

In this way the greater part of the area of the base was covered with blocks varying from 1 foot 6 inches to 2 feet 6 inches in thickness, but between them were small interstices which had to be filled in without the protection of the tarpaulin. In these cases, when the tide was at its lowest, a mass of concrete was collected on the edge of the hole and then thrust quickly into it. If not sufficient to fill it, more was added to it above water, and the base was trodden out so that the same face was always exposed to the water. The concrete so deposited appeared to be quite as perfect as that laid in the tarpaulins. The whole space was then brought up to a thickness of about 2 feet, when the surface was dry at low water, and the sleepers were next fixed under the shoulders of the piles, and the deposit of the native concrete commenced. This had been mixed dry, in the proper proportions, at Suez, and it was watered as it was discharged from the vessels. This was a troublesome process, and certainly not so favourable for making a good concrete as the general practice of watering a few days before deposit, but the result was successful, an excellent block being ultimately formed. It served as a wharf alongside which the lighters could lie to discharge their loads of ironwork, and upon which the iron-work could also be laid out in proper order.

The Author remained with the 'Union' until the island establishment was complete, and the success of the process of depositing the concrete was well assured. He then left the Ushruffee works entirely in Mr. Scott's hands, and returned to Suez to take on board the materials for the Dædalus.

On the 19th December, 1861, the 'Union' got under weigh for the Dædalus. After waiting three days at Ushruffee, to complete some repairs to the ship, she made the Dædalus at 3 p.m. on the 26th December, having spent several hours in searching for it. A lighter had been towed down from Ushruffee, and this was immediately laden with the materials first required. It may be remembered that a small sand-bank of triturated coral was described as existing upon this reef. A site for the lighthouse was chosen near this bank, as it had been determined to use the sand in the formation of the concrete, and it was also convenient for beaching boats, and other temporary purposes.

The surface of the reef is less favourable than that of the Ushruffee for building on, as it consists of an irregular alternation of coral lumps and hollows partially filled with sand. The coral lumps, however, are all at the same height, and the hollows are of nearly the same depth, being from 18 inches to 2 feet below the upper level of the coral.

A four-legged shears was set up on the intended site, and a platform fixed upon it, at the level of the under side of the pile-collars. Upon this platform were laid and bolted together the plates forming the polygon to connect the inner circle of piles. The six piles were then successively raised on end, by means of a light three-legged shears, easily moved from one to the other, and the collars were bolted to the polygon. When the six piles were fixed in place, the original stage was removed, and a new one was formed to receive, in a similar manner, the outer polygon. This having been fixed in place, and the two polygons connected by the radiators joining their corresponding angles, the outer piles were raised. The caisson plates were then set up to receive the concrete, being first bolted together, and as far as the water would allow, riveted, to prevent the loosening of the bolts by the shock of the sea. The whole of this operation occupied seven days and a quarter, or, (including Sunday the 29th,) till the evening of the 3rd January, 1862.

The staff employed consisted of four civil workmen, and working parties of six to eight men from the crew. During this time the duties on board were more arduous than those on shore, but they were carried out by Captain Kirton with admirable judgment and nerve. Whenever the wind was steady from the northward, he laid out a long coir-rope warp to an anchor on the reef, by which the ship hung on at a distance of about 200 fathoms from the edge. A current of about 1 mile per hour generally set her out a little to the eastward, which brought her into an awkward rolling sea, rendering the discharge of materials over the side into the lighter an operation of some difficulty. Here, however, was proved the advantage of the lightness of the pieces of ironwork, and the piles could be thrown overboard and towed ashore. When the wind was unsteady, or from the southward, it was necessary to keep under steam. On leaving work at sunset, two lights were always suspended upon the lighthouse staging, which, burning till about midnight, gave the ship's position ; but during the morning hours, after the lamps had gone out, the ship, unless hanging to the reef, was apt to drift out of sight, and an hour, or two would be lost in recovering her position after daylight.

Immediately on the conclusion of the work on the evening of the 3rd, the lighter was moored upon the reef, and the party returned to Ushruffee, where they arrived on the 5th January.

On the 10th the steamer again started, having now on board 50 tons of cement and twenty Arab labourers, under a native foreman, for depositing the concrete, and with a second lighter in tow. Bad weather coming on, she was obliged to shelter for two days under Jubal Island, and did not reach the Dædalus till half-past 2 p.m., on the 14th. The lighter was immediately loaded with 5 tons of cement; but the tide would not allow of her floating over the reef to the lighthouse that afternoon, and a commencement was not made until the next day.

The concrete here used consisted of three and a half measures of coral sand to one measure of cement.

The first operation was to fill up the holes between the coral lumps, with coal-bags containing concrete, so as to make an even surface upon which to lay the tarpaulins. The deposit was then carried on in the same manner as at the Ushruffee. The result, however, was not quite so satisfactory as to the quality of the concrete, owing to some difference in the cement, so slight as not to be noticeable for ordinary dry work, but probably involving the very qualities which are especially required for hydraulic concrete. It was for some time feared, that a more permanent casing than that afforded by the caisson plates would have to be provided; but during the twelve-months that followed its deposit, the concrete improved so much, that it is probable no such protection will be necessary. Unfortunately, the quantity of cement was only sufficient at that time to complete three-fourths of the required height of the block. This occupied eight days, and on the evening of the 23rd January, the 'Union' again started for Ushruffee, leaving the two lighters moored on the reef.

On arriving at Ushruffee, after a stormy passage of three days, it was found that five tiers of that lighthouse were erected and partly riveted. It might, therefore, be said, that the once doubtful parts of the operations had now been successfully accomplished, and as there was no further need for the services of two superintendents, the Author handed over the whole conduct of the undertaking to Mr. Scott, and returned home.

At Suez, the 'Union' received on board the materials for the superstructure of the Dædalus, and on the 13th February, at Ushruffee, Mr. Scott and his party, consisting of four mechanics, two riveters, four mechanics' labourers and ten Arabs, in all twenty men besides the crew. The European force had been reduced by the illness of two of the riveters, one of whom had to be sent home, and the other was left at Ushruffee.

The steamer arrived off the Dædalus on the afternoon of Saturday the 15th, but a heavy sea breaking upon the reef, prevented any landing till the 17th. From that day, however, the work proceeded systematically and rapidly, notwithstanding a

more than ordinary amount of sickness among the workmen, until the 13th March, in all twenty-six days, during twenty-one of which the work was carried on. By that time the whole of the framework had been erected and riveted together, two floors and the water-tank completed, and the lower room enclosed. Two mechanics and four seamen were then placed in the building, with a supply of provisions and water, to continue the work, and the 'Union,' with Mr. Scott and the remainder of the working party, returned to Ushruffee. Thus in thirty-seven working days the main portion of this building, now 57 feet high, was so far advanced as to be habitable for a party sufficient to complete the remaining details.

If the ship had been rather larger, so as to have been able to carry the whole of the materials, about 200 tons, in addition to the necessary provisions and stores, these thirty-seven working days might have been continuous, in which case the whole would have been accomplished during an absence of about seven weeks from Suez.

Thus what may be termed the nautical part of the undertaking was completed, and the Author cannot but bear his testimony to the admirable manner in which a very arduous duty was carried out by Captain Kirton. But for his skill and unceasing watchfulness by night and day, the time required for finishing the work might have been much extended, and that extension would have led to other complications, the effect of which would have been to show a very different result from that now presented. Unfortunately the constant strain was too much for his health, and he was forced to return to England in a feeble state, from which he did not recover for many months. The Author is happy to state, however, that he was able in the following autumn to return to the scene of his labours, and devote himself to the organisation of the service for the maintenance of the lights under the Peninsular and Oriental Company.

In the month of April, the 'Union' made another trip to the Dædalus, with Mr. Scott on board. The hot weather had then fairly set in, and Mr. Scott wisely decided that it was desirable not to risk the health of the men, and possibly the chance of completing the Ushruffee, by continuing the work. He therefore deposited the materials for the lantern and light apparatus in the building, brought off the men, and returned to Ushruffee.

The 'Union' was then released from her attendance upon the lighthouse undertaking, after a service of five months and a half.

The sequel of the Dædalus works may be told before returning to those of the Ushruffee. In October, 1862, Thomas Wildey, a leading mechanic from Messrs. Wilkins, who had been engaged in both

the previous expeditions, two of the labourers of the last party and five seamen, left England for Egypt, and having been conveyed to the Dædalus by a steamer lent by the Egyptian Government, were left there in the beginning of November to complete the work. The light was exhibited on the 1st February, 1863, and a few weeks afterwards this party were brought away.

At the last mention of the Ushruffee, the concrete base was completed and five of the eleven tiers of framing erected. Such was its state when Mr. Scott and his party started for the Dædalus in the middle of February, 1862. On that occasion he left behind the European boat's crew of six men, who were engaged during the month of his absence in conveying the remainder of the materials to the reef, and in sorting them upon the concrete base. It was fortunate that this arrangement had been made, for after the greater portion had been landed, one of the lighters broke from her moorings during a gale, and was lost at sea, leaving only one to complete the transport.

By the time of Mr. Scott's return, on the 15th March, the places of the two sick riveters had been supplied from England. The erection then proceeded rapidly, in the face of much difficulty, from almost constant high northerly winds, which made the daily voyage to the reef a work of great labour and sometimes of danger; but the Author believes scarcely an instance occurred of the voyage not having been attempted, though it was not an unusual circumstance for the party to beat about for two or three hours without making any way, and then return to shore wet to the skin. However, energy and perseverance were rewarded. The structure was erected up to the lantern level by the 5th April, and the whole of the main framing was riveted before the close of the month.

As the erection above the top of the piles was commenced on the 6th January, and there was a month of intermission of the work, while the party were absent at the Dædalus, the time taken in erecting the skeleton framework, 106 feet in height, was two months, and the riveting was completed within three months. But for the want of riveters at the commencement, the time would probably have been a fortnight, or three weeks less. The months of May and June were occupied with the erection of the lantern and light apparatus, and in perfecting the details of the building.

These works were carried on under still greater difficulties, from stormy weather, than previously; but on the night of the 1st July the light was exhibited.

During the prosecution of the works there was not a disabling accident to any European, and there were only two, or three slight casualties among the Arabs. The whole of the materials were

also landed at both lighthouses, during the second expedition, without damage, or loss.

In connection with this undertaking, though not in consequence of it, the profession has to mourn the loss of a very promising member. A few days before the arrival of the steamer which was to convey the party back to Suez, Mr. Scott was attacked with diarrhœa and dysentery, to which he was unable to apply the necessary remedies. He arrived at home in a very weak state, and the attack developed the seeds of a disease of long standing, under which, five months later, he succumbed. For the last few weeks of his stay at Ushruffee, his duties had been much increased and his anxieties aggravated by the loss of the services of Dr. O'Neill, who had been obliged to return to England through illness. It is remarkable that though three of the chiefs of the expedition,—Captain Kirton, Mr. Scott, and Dr. O'Neill,—all left in illness, yet as a rule the climate appeared to agree well with the English workmen, who, with one exception, returned in good health.

With regard to the cost of the undertaking, a statement of the total amount expended upon the construction of the two lighthouses, in all £55,211, would give a wrong impression unless accompanied by an explanation.

The cost of the whole, as an Engineering work, independently of the employment of the steamer, may be taken at £32,079. This represents what the cost would have been if the reefs, instead of being 150 miles and 350 miles from Suez, had been within a boating distance of that place, say $1\frac{1}{2}$ mile and $\frac{1}{2}$ a mile respectively. It includes all contingencies of every kind, except such as were incidental to the long sea voyages beyond Suez.

Again, if it had been possible to have equipped the steamer at Suez, and employed her continuously for the time during which the work required her assistance, the cost would have been £10,003, making the total cost of the undertaking, on this supposition, £42,082.

The remaining expenditure, £13,129, was of an entirely exceptional kind, mainly incidental to the equipment of the ship from Bombay instead of from Suez, and other special conditions affecting the nautical part of the undertaking.

The Paper is illustrated by a series of diagrams, from which Plate I. (Figs. 1 to 16) is compiled.

[Mr. Parkes

Mr. Parkes said, that in order to reduce the time occupied in the reading of the Paper, it had been necessary to omit several matters of detail. It would be seen that in these designs some unusual features had been introduced, to meet the conditions to be fulfilled. The lighthouses, therefore, were not intended as examples applicable to other situations; at the same time, he thought no other existing system of lighthouse construction would have been suitable in these places. In reply to an inquiry, Mr. Parkes stated, that the cost of the lanterns was included in the sums mentioned in the Paper.

Mr. Alexander Gordon was much gratified with the Paper, and with the recognition given to the services of the late Mr. C. W. Scott. Mr. Gordon had had the advantage of Mr. Scott's co-operation in some difficult undertakings, and he had always found him a man of first-rate ability, of great endurance, and of wonderful decision of character. Mr. Scott had previously experienced in the Bahamas, difficulties analogous to those met with in the Red Sea, and he was therefore well prepared to encounter them.

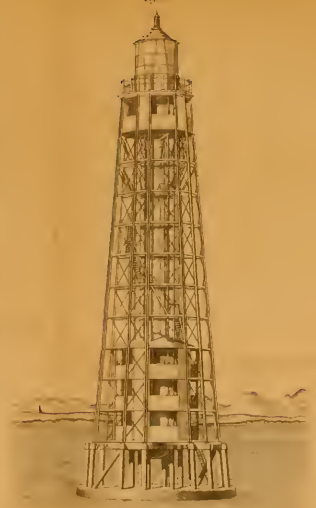
The essential and peculiar feature of the Red Sea Lighthouses was the foundation. How far dependence could be placed upon concrete made with Portland cement and sea water, it was difficult to say; and he might, probably, be excused for expressing a doubt as to the foundations of the Ushruffee and the Dædalus Lighthouses, by references to facts well known to Engineers in India, with respect to the parts of wooden structures between wind and water. The wooden piles must be closely looked to, for, judging from the experience gained in the East Indies, they would be liable to fail at the places where they came out from above the concrete. The superstructure of wrought-iron framing, reminded him of some features in the work of Mr. J. W. P. Lewis, at Cay West, on the Florida Reef. Having to contend with the same doubtful foundation, Mr. Lewis did not have recourse to timber, but he used iron screw-piles, and screwed them deeply into the débris of the coral rock. Upon that he built his structure in cast iron, diagonally braced with wrought iron, perfectly rigid and good, to even a greater height than 144 feet. All the upper work of the Ushruffee and the Dædalus was sound, and would be durable, no doubt, if kept well painted; but the uncertainty was, whether the wooden piles would stand. If some of them once got adrift, he should fear they would act upon the others, and eventually knock down the whole.

A comparison had been made between the vibration of the structure at the Ushruffee and the lighthouses upon which Mr. Scott was engaged in the Bahamas, under Mr. Gordon's directions. The Ushruffee Lighthouse was 144 feet high; but it should be borne in

RED SEA LIGHTHOUSES.

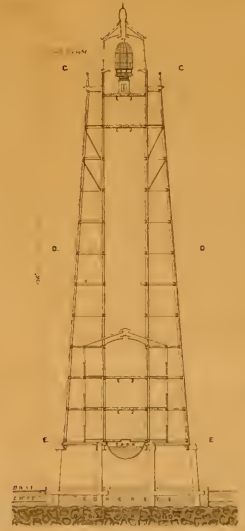
Fig. 1

Fig. 2



PERSPECTIVE VIEW

Fig. 3



SECTION

USHRUFFEE LIGHTHOUSE

Fig. 6.

PLAN OF PEDESTAL AT C.C.

Fig. 5

PLAN AT D.D

Fig. 4

PLAN OF BASE AT E.E

Fig. 16

DAEDALUS. — THROUGHOUT
USHRUFFEE. — TIERS 8 9 10 11 12.

Fig. 15

USHRUFFEE. — TIERS 4 5 6 7

Fig. 14

USHRUFFEE. — TIERS 1 2 3.

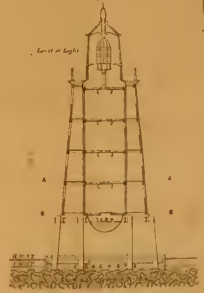
Fig. 7

PERSPECTIVE VIEW

Fig. 13

CONNECTION

Fig. 8



SECTION

DAEDALUS LIGHTHOUSE.

Fig. 12

PLAN AT F.F.

Fig. 11

ELEVATION

Fig. 10.

PLAN AT A.A

Fig. 9

PLAN OF BASE AT B.B

mind, that the Lobos Cay Lighthouse, in the Old Bahama Channel, built upon a foundation of disintegrated, or broken coral rock, was higher. If the statement were correct (which he doubted) as to the relative vibration of the two lighthouses, that was in some measure to be accounted for, by the greater altitude of the Lobos Cay Lighthouse, and the hurricane climate in which it was placed. Again, the whole of the island of Lobos Cay was probably far less solid than the ground on which the Ushruffee Light stood; the former, consisting of only half an acre to an acre in extent, was continually shaken by the action of the sea, and every blow of the pile-driving machine in laying the foundation, vibrated over the entire island.

The cost of the two lighthouses was stated in the Paper to be £55,200; the total cost of that on Lobos Cay, which was 160 feet high instead of 144 feet, and was also lighted, like the former, by a fixed apparatus of the first order of Fresnel, was only £22,419; there was thus a considerable difference in favour of the Bahama structure in point of cost.

The cost for the illuminating and optical apparatus of the three Red Sea Lighthouses was about £6,000. Now about the same time that the Red Sea Lights were in progress, Mr. Gordon had sent out from this country an apparatus of the first order, to be put up, under the directions of Colonel Collyer, in the Malacca Channel, the cost of which was only £1,500.

It had been stated in the Paper, that the revolving cowls for the purposes of ventilation, had sometimes failed; but this could be accounted for. In many, indeed in most cases, the Trinity House allowance for the escape of heated and foul air at the top, was, for the first order of lights, only 70 square inches. Mr. Gordon, however, had never used less than 153 square inches, and the sponges were never required to wipe the dew from the interior of the glass; the atmosphere was always pleasant and good. He had put up these cowls in his lighthouses, which were mostly situated in tropical and hurricane climates, and he had never found any inconvenience from them. There had been cases of other cowls standing still, which had been caused by the neglect of the workmen, but no cowl with such a large passage as he used, had stood still in any gale of wind.

There was one other point to which he would refer. The illuminating apparatus, manufactured by Messrs Chance, was very exact and beautiful, but there was a much cheaper mode; instead of using cut plate-glass, which was necessarily thick and costly, to press up from steel moulds flint glass, or crystal. In this way there was a thinner substance for the light to pass through, and therefore, a clearer light, was obtained; as also a perfectly accurate beam, or an accurate azimuthal light, if such

was required. Colonel Collyer had informed him, that a light of that sort, which Mr. Gordon had sent out to Rachadah, in the Malacca Channel, had been perfectly successful. It was seen as far as, and he believed farther than, any of the Fresnel lights. He gave, however, full credit to M. Fresnel for cutting up the bull's-eye into steps, as Buffon and Brewster had proposed, in order to lessen the thickness of glass which obstructed the light; and in this new process, M. Degrand, of the Ponts et Chaussées, when assistant to M. Renaud, the head of the Lighthouse Department of France, had merely followed out the views of M. Fresnel. M. Degrand had perfectly succeeded in that arrangement; and Mr. Gordon thought that Lighthouse Engineers would, by adopting it, get refracted light at a much cheaper cost than hitherto.

A compliment had been paid by the Author of the Paper, to the "official energy" of the Government in the instance of the Red Sea Lights. So far as the statement of accounts went, the Board of Trade was perfect; but he could not give them the same credit for their interference in the matter of Lighthouse Engineering.

Mr. VIGNOLES inquired what description of wood was used for the piles. He was not sufficiently acquainted with the locality, to know how the action of the wind in a gale would affect the structure, or whether the worms would get to the wood: and he was desirous of having some explanation of the reason why wood had been preferred to iron.

Mr. PARKES replied that the piles were of the best Malabar teak, and in the position in which they were placed, they could not be affected by the worm, as they were above the level of high water. If the piles had not been of wood, the alternative would have been cast or wrought iron. The former was of doubtful duration when exposed to sea water. If there had been any real advantage in the use of cast iron, there would have been no fear in employing it; but there was a practical advantage in the use of timber. In the first place, the piles were cheaper, and there was greater facility in adjusting them to an exact level, because timber could be cut, where iron could only be chipped; moreover, from the buoyancy of timber, it was easier to get the piles from the ship to the spot where they were to be erected. He thought the only feature to be set against these advantages was the question of duration. Teak was, however, a very durable material, perhaps not so much so as cast iron, but even that was not perfectly durable. Another advantage was, that any one of the piles could, if necessary, be withdrawn, and another substituted for it without disturbing the superstructure.

In reply to a question, Mr. Parkes said, that the concrete which formed the base was made with salt water.

Mr. VIGNOLES suggested whether, granting the explanation to be satisfactory with regard to cast iron, a succession of wrought iron cylinders connected by flanges, would not have offered all the advantages the Author had assumed with respect to lightness and facility of transport, and have avoided the inconvenience of cast iron. He did not make these observations in a captious spirit, but as he was about to engage in similar erections himself, he was anxious to know the reasons which had induced the Author to carry out this particular plan.

Captain ARROW observed, that the building of these lighthouses was more an engineering subject than one coming under his own immediate knowledge, but he felt great interest in the Paper, and he thought that the difficulties of carrying on any work in such a climate were so great, that the element of cost could not be so closely considered as it might be in England. With regard to the lighting apparatus, it had been brought forward as an element in favour of the moulded lenses of M. Degrand, and the accuracy that was obtained from them, that they were more economical than the apparatus made in the usual way. But cheapness was not an element which could be admitted in optical science, for the best instrument more than repaid the additional money that was expended upon it. He had seen several of these lenses, and he had yet to learn that any kind of glass could be made which could bear comparison with the beautiful instruments manufactured by Messrs. Chance, Brothers. It was a credit to this country, that the manufacture of these instruments had been brought to such perfection, and that the monopoly should have been taken out of the hands of the French manufacturers. The optical skill, and the great energy displayed by Messrs. Chance, were beyond all praise; and the mathematical accuracy obtained was such as could only be properly appreciated by those who were intimately acquainted with the subject. He had had the pleasure of meeting M. Degrand as well as M. Renaud, the French Ingénieur-en-Chef, but he was not aware that either in France, or in this country, the moulded glass apparatus had been tried, except in lights of the smaller orders. The errors in those lights were not cured. The smaller the lights, the less would be the errors; but when the system was applied to one of the large lights, the errors, which were trifling in a small light, would then be exaggerated and become serious. Mr. Gordon, in speaking of the bull's-eye of a lantern as analogous, had hardly done justice to the subject. It certainly was a transmission of light through a thick surface, but instead of merely cutting steps in that surface, the refractors were a work of great mechanical skill, and produced a result which he believed the moulded system could never accurately attain. The attempt on the part of M. Degrand to

introduce economy was undoubtedly praiseworthy, but although he might be comparatively successful in minor lenses, Captain Arrow doubted whether his plan would fulfil the objects of the Trinity House, or compete with the perfect system now in use.

Mr. GORDON observed, that Degrand's system had not been exclusively confined to the smaller order of lights. The one at Rachadah, in the Malacca Channel, was a first-order light.

Mr. E. A. COWPER said, many years ago, his father had made some observations in a discussion upon the Maplin Sand Lighthouse, which was described as being liable to a reciprocating rotatory motion at the top of the tower, and he exhibited a small model, in which the diagonals could be introduced, or withdrawn. Those diagonals, which were not from the outside to the centre, but round the outside, were introduced into the lighthouse, and they at once made it rigid and firm. The Mucking Sand Lighthouse and that at Sea Reach were originally constructed without diagonals, but at his suggestion they were employed, as it was found that the top of the lighthouses would not resist a force tending to produce torsion, or rotation. It was a curious feature in the Ushruffee Lighthouse, that it had diagonal iron ties in every floor except the bottom one, where there were, certainly, two slanting struts of timber, but one only of these could fully come into action at once, and would then cause a side motion in the lighthouse. The Bishop Rock Lighthouse was constructed in the same manner, and it unfortunately gave way at the point where the diagonals were wanting. This had caused it to be assumed that iron was bad for the purpose, and a stone structure had been substituted at about double the cost. For his own part, he considered the introduction of a complete system of iron diagonals indispensable in all iron lighthouses constructed of pipes, or piles. In cast-iron lighthouses every plate formed a diagonal, and he believed that when they were of a reasonable thickness, and were well bolted together, they were far stronger than stone; and if the iron was occasionally payed over with tar, it would last a long time. The principle of iron lighthouses was the proper one for this country to adopt. There were many places where, it was well known, a lighthouse was urgently required, and had not been erected solely on account of the cost; now the expense of iron lighthouses was less than one-half that of stone; he hoped, therefore, that the Trinity House would order the erection, in that material, of more of these safeguards of navigation.

Mr. BOWER, of the firm of G. Forrester and Co., the manufacturers of the Red Sea Lighthouses, said, that as the Author of the Paper was frequently present during the operation of erection on their premises, he was quite capable of replying to any inquiries. So far as the diagonals were concerned, they were specially con-

sidered with reference to the twisting motion, and he believed the system was carefully carried out from the top to the bottom, with that special view.

Admiral Sir EDWARD BELCHER remarked, with reference to the teredo, that it had been assumed it only worked under and at the surface of the water; but every one who had been in Africa, and other tropical climates, where mangrove was cut for firewood, knew that the attacks of the teredo extended as much as 9 feet up the trunk of the tree. On the River Guyaquil, the worm passed through the banks to the surface of the soil which was traversed by salt water only during high tide. But wooden piles were also subject to the ravages of the white ant, or termites, which had often been found on off-lying islands in the South Eastern Archipelago, but especially in Africa. In the year 1831, he had witnessed the sudden fall of a 32-pounder gun at a fort on the Barra side, opposite the town of Gambia. On entering the battery the carriage seemed to be perfect; it was newly painted, and was apparently firm. He had occasion to stand on the hinder truck to obtain a clear view, when the whole carriage crumbled, leaving just about the proportional remains of wood as would agree with the cellular divisions of the honeycomb, and he was unable to find any portion which would afford a clue to the nature of the wood of which it had been constructed. The Governor informed him that it was of iron-wood, which was harder than African oak. Between, therefore, the termites and the teredo navalis, he much feared that the wooden piles of the Red Sea Lighthouses would not endure long. It was desirable to be informed whether, before decortication, they had been injected by any of the mercurial, zinc, or other preparations.

Mr. DOUGLASS inquired the height of the waves in the Red Sea, observing that at the Bishop Rock he had seen waves of 40 feet go over the platform.

Mr. FLEEMING JENKIN inquired, what was the mean temperature in the lighthouses, and how far the arrangements for keeping down the temperature had answered.

Mr. J. H. PORTER said, the Author had explained the facility with which a defective pile might be unshipped, but to his mind it was not satisfactory that the superstructure should stand within, instead of upon, the piles. There might be sufficient resistance to the shearing strain upon the supports of the bottom frame, but he thought the general aspect of the structure was, in this respect, hardly satisfactory. With regard to the diagonal bracing constituting its main support, he was not sure that Mr. Cowper's remarks had been quite understood. The diagram exhibited did not show clearly what diagonals were carried round the exterior of the structure. He recollected a discussion at the Institution of Me-

chanical Engineers[1] on the subject of lighthouses of a similar character to these, in the course of which allusion was made to a lighthouse 150 feet in height, which he had constructed for the Spanish Government; and on that occasion, Mr. Cowper made some interesting remarks upon the importance of diagonals round the structure. It was, in his opinion, an important element in resisting any tendency to torsion.

Mr. PARKES said, that the waves at some distance within the edges of the reefs were completely broken. Close to the lighthouses they were trifling, and there was nothing more than a little wash over the platform. The depth of water over the reefs at high tide did not exceed 4 feet for 100 yards from the lighthouses, in any direction. There was no comparison, as regarded the force of the sea, between these structures and those erected by Mr. Douglass on the English coast.

Mr. G. W. HEMANS remarked that the Paper gave an interesting account of an engineering work of considerable difficulty, which had been surmounted with great ingenuity. The work being at a distance, and as he had never seen the ground, or any similar locality, he felt some hesitation in offering criticism upon it. Still he could not but regret, that a work of so permanent a character as the iron structure should have been established upon a foundation which was obviously of a temporary and perishable character; nor had he as yet heard any adequate explanation of the reasons for putting an iron structure of that importance upon wooden legs. In the meantime, it seemed to him that a simple remedy might be suggested for what appeared an incomplete arrangement. He thought that having regard to the slots for wedges in the tops of the wooden piles, which allowed the entrance of water, the attachments of the iron framework to the pile heads, particularly where they were subject to alternations of heat and to the spray of the waves, ought to have caps to protect them from rain water, and that instead of shearing pins, the collar should be secured by through bolts. He would further suggest, as it was certain that sooner, or later, the wooden piles, though of teak, must decay, it would be easy to encircle them with boiler plates riveted and built in cylinders round the piles. If these were $\frac{1}{4}$th of an inch thick and 4 feet diameter, they might be built to the top of the piles. Then the space between the pile and the plates might be made up with concrete of the best description and carried up flush to the frame of iron-work above, and the whole surmounted by an iron cap. He believed that the whole of the work for each pile would not cost more than about £60. The structure would then stand upon eighteen solid columns of concrete equal to rock, sur-

[1] Institution of Mechanical Engineers. Proceedings, 1861, pp. 15–29.

rounded with a casing of wrought iron, and an inside bearing of teak. By this means the external appearance of the structure would not be damaged, whilst it would be greatly improved as to durability. He was not aware whether it was generally known, that the new Westminster Bridge rested upon foundations similar in character. The solid stone piers which carried the iron arches, rested upon the tops of wooden piles which stood a considerable height above the bed of the river. Those piles were within cases composed of cast iron and granite slabs, and around the piles and filling up the sides of the casing, there was a solid bed of concrete as good as rock. Fault had been found with that construction during its progress, but he believed that mode was perfectly satisfactory, and that in future, the same plan would most probably be carried out, under similar circumstances, for works in the bed of a river at low water. The Red Sea Lighthouses might be made satisfactory in all respects by the adoption of a similar expedient.

Mr. J. G. Cockburn Curtis said, it was now so many years since he was in a vessel navigating the Red Sea, and the Paper seemed to him so clearly drawn up, that he should not have done more than have expressed his thanks to the Author, as an old sailor glad to see lighthouses established wherever danger existed, and as a Member of the Institution, glad that an able and minute record had been given of the execution of works under peculiarly difficult circumstances. But some remarks were made in the course of the discussion which, it appeared to him, must have arisen from a misappreciation of the peculiar circumstances of the sites upon which these lighthouses were erected; and as it might be possible that the nautical difficulties of the undertaking and the different local characteristics of the Red Sea coral reefs might not have been delineated with sufficient clearness, he would offer a few observations on those points.

This appeared to be a case in which the nautical difficulties of the undertaking were peculiar. He would pass over the lighthouse on Zafarana Point, which did not present any nautical difficulties, and come to that on the Ushruffee Reef. This reef, as the Author had correctly described, was situated on the western side of the navigable channel of the Straits of Jubal, 150 miles from Suez. It formed a portion of a series of reefs, and was possibly the most dangerous part of the navigation. The Ushruffee was a coral reef of which the sides sloped irregularly, from the level of a few inches under low water to a depth of from 8 fathoms to 10 fathoms, no part being above the water, and there being very little sand, even in the cavities of the coral. To this he must add, that there was indifferent anchorage, and that the north-west swell broke with great violence on the reef. There was a range of tide of about 5 feet, and at times a rapid current, and the channels

were so dangerous and intricate that, in the year 1831, the Indian ship 'Samarang,' while passing to the southward, was wrecked in one of them, even with a fair wind.

The next reef was the Dædalus. This was correctly stated as being situated in the middle of the Red Sea, 350 miles from Suez, and 180 miles from the entrance to the Gulf of Suez. It was 45 miles from the western shore, 55 miles from the eastern shore, and 45 miles from the nearest soundings: therefore it was quite impossible for any vessel to obtain anchorage near that reef. Soundings had been taken to the depth of 260 fathoms alongside it without reaching the bottom. The sand bank in the centre, according to the best authenticated statements, was periodically washed away when the sea rose and the wind blew strong. There were no harbours and no towns along the coast, and fresh water could only be obtained by distillation. If an ordinary sailing vessel were to hook on to the reef, she would be in great danger of getting foul of it, if the wind changed, or grew light. It would be a difficult matter even for a steamer to hook on to it, and when standing off and on, so soon as the light was low, the vessel would be under the necessity of regaining the reef by the compass bearing, which was, to say the least of it, a very nice operation in a locality where there were uncertain currents of as much as 1, or $1\frac{1}{2}$ knot per hour. Looking at the peculiar difficulties of the case, he thought the Author had good reason to speak in terms of the highest praise of the manner in which what might be termed the nautical part of the undertaking, had been carried out by Captain Kirton.

With regard to the objections which had been urged, as to the mode of obtaining the foundation for the superstructures, few persons who had not had an opportunity of minutely examining coral reefs, could understand the difficulty which was presented to the view of an Engineer by the peculiarly brittle structure of a coral reef;—a structure which varied in the case of almost every individual reef, the slightest force being sometimes sufficient to crush down, or break off a piece of the coral. In looking at all the circumstances, the course pursued by the Author, that of building the structures on the surface of the reef and not sinking into it, he considered to have been the wisest; as also that of keeping the weight of the superstructure as light as possible. As regarded the employment of concrete, he saw no objections to its use; and structures which he had seen on coral reefs gave no reason to suppose, that the plan adopted would be unsuccessful. Two alternatives had been suggested in the course of the discussion, those of wrought iron and cast iron. He should be sorry to attempt to put down screw piles into the coral reefs of the Red Sea, for fear that they might give way during the process of sinking,

or at the still more dangerous time when the superstructure was erected. The known liability of wrought iron to oxidation, when exposed to the action of salt water, was a serious objection. He would much rather have a pile where it was exposed, and where he could see the deficiency, than have wrought iron beneath a coral reef where he could not discover the defects. As regarded cast iron, he thought there was not sufficient experience to warrant the use of it in such a situation. It must be remembered, that cast iron there came into contact with the salt water, though it was covered over with concrete; when placed upon the tongue, there was a perceptible saline taste in the specimens of concrete exhibited upon the table; so that the question to his mind was, whether it was advisable to have a pile lasting certainly for ten years, or whether an uncertain material should be used, which, possibly, might last for twenty years. It should not be forgotten, that if there was any damage in this case, it was all in sight and could be at once seen, and be easily repaired and remedied. A valuable suggestion had been made, that the pile-work might be built in solid, or a ring of iron placed round it, if any deficiency occurred; he thought, however, that for at least ten years, no deficiency would occur. An objection had been taken to the want of diagonal bracings, and it was stated that the Bishop Rock Lighthouse failed from a similar deficiency. But that objection only afforded another illustration of the necessity in all engineering matters and comparisons of attending to the locus in quo. The Bishop Rock Lighthouse was exposed to the full force of the Atlantic waves, whereas the lighthouses now under consideration, had half a mile of reef extending from the lighthouse in the direction of the prevailing strongest wind, and the force of the sea was completely broken at some distance within the edge of the reef. In the case of the Bishop Rock Lighthouse, there was a rise and fall of tide of 12 feet; but what was the condition of this lighthouse with regard to the effect of the waves? The strong wind was from the north-west; there was half a mile of coral reef interposed between this lighthouse and the force of the waves; yet it had been argued that this structure was in danger of being knocked down by them. It would be at once seen, that the cases of the Bishop Rock and the Ushruffee and the Dædalus were widely different.

Another point involving the nautical question was that of the cost, and he ventured to offer a few remarks upon that in deference to the observations of Mr. Gordon, who was, undoubtedly, a great authority on lighthouses. A comparison had been made of the relative cost of the Lobos Cay Lighthouse and those erected by the Author; but there seemed to him to be but little analogy between the two cases. The Lobos Cay Light was only 160 miles from Nassau, the basis of operations for building that lighthouse, where

a sailing-vessel,—not a steamer,—could have been chartered to bring the materials to the Cay at the cheapest rate. The Cay being 3 feet above the level of high water, and the rise and fall of the tide only 3 feet with 4 fathoms close alongside, there was every facility for landing the materials, and making the Cay itself available for storing materials; whereas, in the present case, from the strong winds and currents, a sailing-vessel could not have been used, and no steamer could have been chartered nearer than Bombay; and when the steamer, which was evidently too small for the purpose, was employed, it must be remembered that in the case of the Ushruffee Lighthouse, the basis of operations was an island, $1\frac{1}{2}$ mile from the site, and that boating operations were necessary, involving at least a loss of a quarter of a day on each day's work. He thought that it was very desirable to have a correct comparison of the circumstances under which these lighthouses were built, and of the cost, and for that purpose he suggested, that the Author and Mr. Gordon should give the actual engineering cost of each construction, separately from that of carrying the materials.

Colonel Collyer said, that two years ago, he had put up in the Straits Settlement on Cape Rachadah, a light which had been designed by Mr. Gordon, and that the cost of the lighting apparatus and lantern was only £1,500. It was a first-class great sea light, with four concentric wicks, and the refracting portions of the glass were made by M. Fresnel. He received a report a short time since from the Governor of the Straits Settlement, which stated, that it showed a clear, steady light at 28 nautical miles, the height being 374 feet above the sea. If it showed a light 28 miles in one direction, it would do so in another; and for £6,000, the cost of the three Red Sea Lights, four lights might be obtained, illuminating 224 miles, instead of three lights at the same elevation illuminating only 170 miles. He thought, therefore, so far as the lighting apparatus was concerned, that the light which Mr. Gordon had constructed was cheaper than those put up in the Red Sea.

Colonel Smith remarked, that he was well acquainted with the circumstances of the contract just alluded to, and was therefore able to confirm the statements which had been made by Colonel Collyer.

Captain Maury said, with reference to the efficiency of the lights, that he apprehended it was in some measure dependent upon meteorological conditions. He imagined a good light ought to be seen as far as the tangent of the earth's surface would allow, and the intensity of the light required to be seen at that distance varied in different latitudes; so that although a light which had been described as being sent through a particular

kind of pressed glass, might answer very well in tropical, or in other latitudes where the atmosphere was seldom thick, or muggy, yet in other parts of the world where the state of the atmosphere was different, he thought lights of greater intensity, such as Fresnel's best, would be required.

With regard to the Dædalus Lighthouse, it was stated to be situated in the centre of a shoal, which suddenly rose up from the bottom of the Red Sea to the surface, and upon which the sea broke before reaching the structure. Now any one who had cruised among the coral islands of the Pacific, must have been struck with the effect of those so called natural breakwaters, the coral reefs. In illustration of this, he might mention the Society Islands,—Tahiti, for instance,—which was surrounded by a coral reef not quite reaching to the surface, but always a little below; and it was marvellous to see the rough sea foaming and tossing outside the reef with nothing visible to make the smooth water inside. He had been in parts of that ocean in rough weather, and he had on one occasion, in order to obtain shelter, found it necessary to place the boat on the top of a wave, and so let her jump from a stormy sea into perfectly smooth water. There could not be a better protection to a foundation than was afforded by these reefs forming, as they did, the most perfect breakwater.

Mr. H. Grissell disapproved entirely of the design for these lighthouses. He had constructed many lighthouses, and if he had been consulted in regard to those for the Red Sea, he should not have placed them upon wooden legs.

As regarded the difficulty of transport, he did not see that it was greater in this case, than in many others. He was engaged at the present time in constructing a lighthouse upon the Calf Rock, in the Atlantic, off Bantry Bay, 6 miles distant from any land that could be made use of. The stormy character of the Atlantic was well known, and such was the nature of the water round the rock, that there were only about two months in the course of the year, when materials could be safely landed; yet he had recently constructed upon that rock a lighthouse, 80 feet high, in one month. Very frequently no boat could live near the rock, and several times it became necessary to convey food by means of indiarubber bags to the men who had remained upon the site. The men were now taken off every night, however fine the weather might be, as it was quite uncertain when the opportunity might again occur; indeed, for weeks together it was not possible for a boat to approach the rock nearer than a quarter of a mile; but by perseverance, and taking advantage of each opportunity, the work was effected this year, for one month's continued tolerable weather had been sufficient to erect a tower upon Mr. Gordon's system. With regard to cost, he thought he should have

been glad to have contracted with the Government at two-thirds the cost of these, and to have supplied the light for less than £1,300; the whole work ought, in his opinion, not to have cost, for a cast-iron tower, more than £10,000 or £12,000. He also thought it would have been better to have carried up a granite base for about 10 feet, in order to keep the iron work well out of the water; the cast-iron superstructure would then have stood perfectly well. The lighthouse upon the Calf Rock, to which he had referred, had stood through all the late gales, though it was only in an incomplete state. The rock was 70 feet above water, and the focal plane of the light was 150 feet above the level of the sea, yet the sea went over it, and his men had stated that sometimes they could not see the rock for an hour together. That might perhaps be a little exaggeration, but he was quite sure that, in very heavy gales, it was often not seen for a quarter of an hour at a time.

Mr. VIGNOLES said, with regard to the foundations of these lighthouses, he did not approve of wooden supports, but perhaps the Author might be able to give sufficient reasons for their adoption in preference to any other mode, for there might possibly have been many difficult circumstances to contend with. He was desirous of knowing, in the first place, why iron was not employed; and next, if there were reasons for rejecting cast iron, why wrought iron was not used. If the substratum was as good as had been represented, was it not practicable to carry up the structure to the height of 15 or 20 feet, in stone or granite? It was entirely in the province of the Engineer to appreciate the circumstances under which it would be most advisable to employ either iron, wood, or stone. It was not, in his opinion, of much consequence whether one lighthouse was 20 feet or 30 feet higher than another, the great expense being in the foundations. Although the cost of these works appeared to be high, it must be remembered that they were executed in a tropical climate, and that in all such cases the expense was double or treble what it would be in England. He doubted whether a comparison could be fairly made with, even the west coast of, Ireland, because in the one case all the necessary appliances and assistance were at hand, while in the other they could only be obtained with difficulty and delay.

Mr. GORDON was desirous of learning what amount of the labour employed in the Red Sea was the forced or slave labour of Egypt. As to the floating of the piles, from his experience he could state, that nearly one half of the teak piles he had used, when shod, would not float. He believed that hollow iron piles might have been employed which would have floated.

Mr. PARKES, in reply, said that a doubt had been expressed as to the durability of Portland cement concrete; but for his

own part, he thought experience was in favour of its being not only a durable, but a constantly-improving material. It was well known that, generally speaking, Portland cement concrete, made fifteen or twenty years ago, was now as good as, or even better than, when it was first put down; and he saw no reason why the concrete employed in these works should not stand equally well. Of the two specimens of concrete on the table, the inferior piece was from the Dædalus; and the other, which must be admitted to be of excellent quality, was from the Ushruffee. He had stated in his Paper, that he was disappointed in the result of the concrete at the Dædalus Lighthouse, and that he could not account for the partial failure of it. Until that lighthouse was visited, twelve months after the concrete was deposited, he had some expectation that it would be necessary to put some protection to it; but it was then found, that although where a piece was cut out of the interior, it was not as solid as it should be, yet there was a hard external crust formed upon it, sufficient to resist the little wash of the waves; he had every hope, therefore, that it was a sound structure so far as the concrete was concerned.

The specimen before alluded to showed how a block of concrete might be hard on the outside and yet be imperfect in the interior; in this particular case, however, the hard crust was a sufficient protection. It was to be observed that, from the form of the block of concrete, which was of little height and of large area, it would be easy to renew any portions that might prove to be imperfect. The concrete was formed of three and a half measures of triturated coral to one measure of cement. The coral sand was found on the reef. The specimen from the Ushruffee was, he believed, as good concrete as could be made under the circumstances; though, if he had had the facilities for mixing it in the most approved manner afforded in ordinary situations, it would, no doubt, have been better. The materials themselves were good, but the mixture was not so complete as if it had been made in a pug mill. The proportions were six measures of gravel, including pebbles and sand, to one measure of cement, turned over with shovels by sailors and native labourers, who had never done that kind of work before.

His reasons for adopting wooden piles were given in the Paper, with many other matters of detail. In making use of timber, he did not do so on the ground that iron was entirely inapplicable. He thought iron might have been used, but in balancing the advantages of the two materials, he decided upon wood. He might mention that the original design of these lighthouses was submitted to Linant Bey, an Engineer of great experience in Egypt, and the Director of the Government Department of Public Works. His first remark was "Why do you use

wooden piles?" Mr. Parkes explained his views generally, and little more was said at that time on the subject. After his return to England, Mr. Parkes received a letter from the Consul-General in Egypt, stating that Linant Bey had again spoken about the wooden piles. Linant Bey had not then the drawings before him, and might not have borne in mind the way in which the wood was to be applied. Mr. Parkes wrote to the Consul-General explaining his reasons for the employment of wood, and the letter was translated and sent to his Excellency, who entirely agreed with the Author. Mr. Parkes could not but think, that some of the Members who had in the discussion expressed what he must admit were natural primâ facie objections to the use of timber would, like Linant Bey, find them disappear on more mature consideration of the exceptional circumstances of the case.

The reasons which induced him to use wooden piles were mainly these:—Cast iron was liable to deterioration in salt water. That deterioration might take place very slowly, but he questioned whether the cause of the deterioration could be clearly explained, or how it could be prevented. He believed, that the iron was chemically extracted by the salt from the body of the casting, and the plumbago was left behind; that seemed the ultimate result. There were several structures which had stood for many years in salt water and were likely to stand many years more, yet there were others which had failed. At the best, cast iron was therefore a doubtful material. An objection had been taken to the employment of wood on a ground which had, on the contrary, always afforded him a strong argument in its favour; that wooden piles would decay between wind and water, at the point where they came out of the concrete. Now he looked upon that fact as an element of safety in timber. So long as a pile remained sound at that point, it was certain that the buried part was sound. If it showed symptoms of decay at that point, it then became a question whether it should be replaced by a new wooden pile, whether it should be replaced by iron, or whether the whole system of piles should be abandoned altogether, and a circular wall built up all round so as to make a solid base. But if cast iron was used, there would be no such certainty that the first decay would take place in an accessible part. That point which was the critical point in timber might be perfectly sound in iron, while the buried part might be rotten. The teak piles would remain sound for many years; they made a very firm substratum; he could not detect the slightest vibration in them, when a high wind was blowing; and they did not seem to have the slightest tendency to loosen themselves in the concrete.

In answer to a question from Mr. Vignoles, Mr. Parkes replied,

that there were about 10 feet clear between the concrete and the under side of the collars.

In an earlier part of the discussion he had brought forward in favour of timber, the argument of its buoyancy. He did not say that was in itself a sufficient reason, but it was a greater reason in this particular locality than it would be in almost any other. It was a fact, that at the time the piles of the Dædalus Lighthouse were in course of erection, every pair of hands employed on the operation was costing upwards of £4 per day. A fully-equipped steamer, which was costing about £1,200 a month, had to be maintained, and the greatest number of men that could be employed on the work at a time, was twelve. When men were costing at the rate of £4 per day each, it was some reason for working them to the greatest possible advantage; it would be easily understood how great was the advantage in discharging the materials from the ship, when she was rolling heavily; if the most bulky parts could be thrown overboard and towed on shore, instead of waiting hours, or perhaps days, till the sea was quiet enough to admit of their being lowered by slow-acting tackle into a small lighter alongside. If he had to renew the foundation by putting in fresh piles of wood, or of iron, or by building in masonry, or by casing the piles upon some such system as Mr. Hemans had suggested, the workmen would be quartered in the lighthouse itself, at a cost of from 10 shillings to 15 shillings per day instead of £4; so that even if the wooden piles were looked upon as a merely temporary expedient, there would be good reason for employing them. But he could not look upon the employment of teak as a merely temporary expedient, for it was acknowledged to be a most durable material,—in such a situation almost imperishable. In India teak ships, two hundred years old, were afloat, and the timbers in them were as sound as when they were first put in. In constructions in that country, if protected from the peculiar influences of the white ant on land and the worm at sea, teak would last an incalculable time. He hoped these piles would last for a considerable time; cast iron might perhaps last longer, but it was not of a nature sufficiently durable to justify its being used in place of teak, which had such other strong arguments in its favour. With regard to wrought iron, he did not think pipes of $\frac{1}{2}$ an inch thick, looking at the effect of salt water upon them, would be more durable than the wooden piles. That was his reason for at once rejecting wrought iron; he did not think it could last longer than teak, and unless made very thick, it was quite as objectionable as cast iron, from its liability to corrosion. Some interesting information had been given relative to the habits of the teredo navalis and of the white ant. These facts deserved the attention of Engineers, but he could not conceive that they afforded any ground for the fear, that those

insects could establish themselves to an injurious extent in the piles of either of the lighthouses in question.

With respect to the diagonal bracing, he had felt great anxiety about the possible motion to which attention had been directed. Many structures had stood for a great number of years without any precaution being taken against that twisting motion, and it was difficult to see how it could arise. In the case of the Maplin Sand Lighthouse there was a good reason for it, from the fact of there being a ladder on one side and none on the other side, and when the sea struck that ladder, a twisting motion was necessarily established. In a structure like the Ushruffee, he thought there was danger of a rotatory motion, simply from the imperfection of the workmanship. If one side of the lighthouse was not as strong as the other, it would yield more to the wind, and set up a rotatory motion, which if it once started, would tend to increase rather than diminish; and he had no doubt, acting as it would upon the weakest joints, it would, in time, destroy the whole structure. In order to guard against that, he had introduced, in each alternate side of the polygon, some diagonal braces, and he expected that would be sufficient to check the first attempt of the structure to rotate. That it was sufficient for the purpose, he thought he could give some proof. When the structure was being put up at Messrs. Forrester's yard, at Liverpool, and was raised five tiers high,—it was not placed upon the piles, but the ironwork rested directly upon the ground,—Messrs. Forrester wrote to him to state that it was so shaky that the men refused to go upon it, its want of rigidity being attributed to its not being riveted. The contractors suggested that it should be put up in two heights, but to this the Author objected, being desirous to test its steadiness when standing at its full height, as he was quite sure if it was not steady in the yard, it would not be so on the reef. Up to this time the diagonal braces, though part of the design, had not been put in. They were afterwards put in and bolted up, and the next report he received from the contractors a week later was, that the lighthouse had been raised four tiers higher, and was very steady. That satisfied him that there was then no fear of rotating. After it was raised to the full height, and the diagonals were in place, though the joints were merely bolted, there was, under a strong breeze, a sensible trembling at the top, but nothing approaching to a rotatory motion. The only way in which such a motion could be detected was when a man was drilling holes in the iron at the top; that motion caused it to twist to a slight extent; but only in the top tier in which the corrugated iron was not filled in. It had been remarked, that the diagonals were carried throughout the ironwork, but that in the tier of timber piles there were only two, of which only one could act at a time. He conceived it was a matter of indifference whether six diagonals were put in six

separate sides of the polygon, or whether one, six times as strong, was put on one side of the polygon. All that was wanted was sufficient resistance, at any point in any side of the polygon in the direction of that side. The direction of the diagonals was so arranged, that they would act as struts against the direct pressure of the wind, when in the quarter from which it blew most strongly. The failure of the first lighthouse erected on the Bishop Rock had been alluded to, and that failure had been attributed to the want of diagonals. He believed that there was no evidence whatever to justify any such conclusion as a matter of fact; it was mere supposition, probable or improbable; still he quite agreed as to the necessity of guarding against a tendency to twisting, and he believed he had done so sufficiently in the case of the Ushruffee.

A remark had been made, that the line of the support was not continuous from the ironwork to the piles, and it was suggested that it seemed as though there would be a shearing action between the one and the other. He could not himself see how the structure could yield by that shearing action, because there was immense strength in the collars, and he thought it impossible in a structure like this, to have brought the bearing of the ironwork directly upon the head of the pile. It might have been capped as had been suggested, but it was impossible to bring the bearing upon the top of the pile, because some allowance must be made for the adjustment of the level of the piles, and in some places there was as much as 6 inches difference of level in the surface of the reef at the feet of two piles, and it was necessary to have the means of adjustment to that extent. That was done by the collar on the head of the pile being moved up, or down, and then secured by wedges and screws.

He had been asked whether the arrangements for mitigating the great heat in the structure had been successful. He was sorry to say his reply to that question must be an indirect one, but he thought not the less satisfactory. He wrote to Captain Kirton some time ago with the view of getting information on this subject to lay before the Institution: he was able to state, that the European lighthouse keepers who went to Suez for relief expressed themselves satisfied in that respect; and if Europeans in so hot a climate had thus expressed themselves with regard to iron lighthouses, he thought the arrangements made for protecting them from heat must have been, on the whole, successful.[1]

[1] By subsequent information it appears that the Dædalus is a very favourite station with the men. During the summer of 1863 there was not a day's illness amongst the three, and they were not inconvenienced by the heat. Thermometrical observations were kept, but they have not been received from the Egyptian Government.—W. P.

With regard to the cost of the lighthouses, he observed that, owing to their peculiar position, and to Suez being the nearest base of operations, it was necessary to employ a steamer at great expense, and he might add, that the control of the steamer was not in his own hands; consequently, although he was sure that the Peninsular and Oriental Company did all they could to forward the work, and to do it economically, yet every one knew that the way to have work done economically, was not to allow a portion to be independent of the control of the Engineer. Under those circumstances he believed the steamer cost more than it otherwise would, if it had been entirely under his own orders. He had little control over the nautical arrangements, and he had none whatever over the accounts. He could not enter into particulars, but he might say that nearly one half the amount charged for the steamer was in no way productive to the undertaking. He therefore thought the fair way of treating this matter would be, to deduct from the gross charge of the undertaking the cost of the Peninsular and Oriental Company's steamer, and of some Egyptian Government steamers, which made a few casual voyages. The total expense so incurred, which was due to the remote and peculiar position of these lighthouses, was about £23,000, and if this was deducted from the total sum of £55,000, there would be left for the structures, as engineering works, £32,000: that was to say, £32,000 would have been the cost, supposing that, instead of the materials having to be carried 150 miles and 350 miles from Suez respectively, and the work attended upon by a steamer, it had been possible to have erected them upon reefs, at the same distance from the mainland of Suez that the reefs were from the island of Ushruffee in the one case, and from the ship in the other. It was impossible to separate the two lighthouses, but as nearly as he could state, he thought the cost of the Ushruffee might have been £22,000, and that of the Dædalus £10,000. It was only just to the undertaking to remark, that the Ushruffee was the first of the kind that had been erected, and there were undoubtedly many little extravagances which on another occasion he should be able to correct. No doubt £22,000 was a large sum for it, and he thought the same kind of work might hereafter be executed in a similar place for £2,000 or £3,000 less.

He begged to repeat that he had not brought forward this communication with any intention of making comparisons between his works and those of others. He claimed no superiority for his own, and distinctly repudiated the idea that the principle of construction he had adopted was applicable to situations with which he was not acquainted. A comparison in the matter of cost had, however, been made between the Ushruffee and the Lobos Cay Lighthouses, and a conclusion had been drawn favourable to the

latter. He thought the following view of the comparison would be fairer:—There were several points of similarity between the two structures. Each was constructed in England, each erected in an utterly desert unproductive region which had to be attended by a specially-employed vessel. The arrangements for each were connected with those for another lighthouse, the Dædalus in the Red Sea, the Great Isaacs in the Bahamas. Their heights were not very different, the Lobos Cay being 150 feet above ground, the Ushruffee 140 feet above water; the difference between the respective extreme heights 158 feet above the heads of the piles and 144 feet, arising from the fact, that the foundation of the one was deep, of the other broad, two ways of obtaining the same end on ground somewhat similar in general character but requiring different treatment. Moreover, both structures were erected under the same Resident Engineer. Now for the points of difference:—The Lobos Cay materials were despatched direct to the island on which they were to be erected, and were put up on dry land within a few yards of the workmen's quarters. The Ushruffee materials were sent to Alexandria, about the same distance from England as Lobos Cay, they had then to be transported 240 miles by railway to Suez, then reshipped for the island on which the working establishment was formed, then taken piecemeal by boat one mile and a half across a stormy channel to a detached and submerged reef, and there erected in the water. Both working establishments had to be attended by ship, but special and unfavourable circumstances made this a very expensive requirement in the Red Sea; in the Bahamas it was comparatively trifling. The official return gave £24,000[1] as the total cost of the Lobos Cay, out of which half of £2,400, or £1,200, was for the attendant sailing-vessel, leaving £22,800 as the net cost of the structure, including all expenses except sea attendance, while the cost of the Ushruffee, with the same exception, was £22,000, or rather less than that of the Lobos Cay. If to the difference due to building in the water on an isolated reef 1½ mile from shore instead of on dry land, be added the fact that the Ushruffee was the first of its class, the Lobos Cay an example of a stereotyped design, he thought he might claim the Ushruffee as the more economical work of the two. Still he was not prepared to say that he would have advised such a structure on the Lobos Cay Reef. He believed each structure was well adapted for its own position, and the difference of cost, so far as it depended on the constructive features, and on whichever side the small advantage might remain, was not a material item in the question.

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[1] Mr. Gordon gives £22,419 as the total cost, but this does not include engineering charges, which are included in the returned cost of the Red Sea Lighthouses. —W. P.

It had been asked what proportion of the work was done by slave labour? None, so far as it was under his own control. The Egyptian workmen employed were furnished by the Government, and were paid by the Resident Engineer at rates varying from 1*s.* 6*d.* to 2*s.* per day. At first they were impressed into the service in the ordinary manner of the country, but latterly volunteers were engaged.

November 17, 1863.

JOHN ROBINSON M'CLEAN, Vice-President,
in the Chair.

No. 1,043.—"On the Duty of the Cornish Pumping Engines."[1]

By WILLIAM MORSHEAD, Jun.

CORNWALL may justly be considered as the birthplace and home of the steam-engine. It was for draining its mines, that the engines of Savery and Newcomen were designed; and to the early encouragement afforded by the Cornish miners, may be attributed no small share of the success which attended Watt. The successive improvements in the Cornish engines, all having for their object the saving of fuel, were, at the commencement of the present century, so far effective, that the Cornish engine became renowned for a high amount of duty. It is therefore much to be regretted, that within the last twenty or twenty-five years, during which time vast improvements have been made in almost every other department of engineering, the average duty of these engines, instead of having increased, as might have been expected from the experience of former years, has fallen off considerably. As this is a matter of great importance, from the daily increasing demand for pumping machinery, through the extension of mining enterprise, both at home and abroad, the Author thinks that a few remarks upon it may not be unserviceable, even though no other result be effected than that of initiating a discussion, and thus drawing attention to a subject, which seems, hitherto, to have been comparatively neglected.

He purposes then to point out the extent to which the duty has declined, as shown by the monthly duty-papers, next, to examine the causes of this decline, and lastly, to discuss the means by which it may be remedied.

The plan of registering, by means of counters, the number of strokes performed by an engine in a given time, and thence estimating the duty, was first introduced by Watt. On the expiration of his patent in 1800, the counters were removed; but in 1812–13 they were replaced, on many of the engines, in consequence of statements having been made that the amount of duty had

[1] The discussion upon this Paper occupied portions of four evenings, but an abstract of the whole is given consecutively.

diminished. The system of publishing monthly reports was at this period introduced by Captain Lean, by whose son it is still continued. The beneficial results which followed the adoption of this course are well known; the duty rose rapidly from 17 millions or 18 millions in 1813, to 65 millions in 1841. In 1847, the publication of another duty-paper was commenced by Mr. William Browne, of St. Austle, for the purpose, more especially, of reporting the performance of the engines in the eastern part of the county, but it was discontinued in a few years for want of support. No condensed abstract of those papers has been published, and it has been impossible to collect the old reports in sufficient number to supply the desideratum, so that the results obtained by Mr. Lean can alone be taken as a guide. The following table, kindly supplied by that gentleman, shows, in round numbers, how many engines were annually reported, and the average duty, from the year 1841 to the present time.

Year.	No. of Engines reported.	Lbs. raised 1 foot by the consumption of 112 lbs. of Coal.
1841	50	65 millions.
1842	47	66 ,,
1843	43	67 ,,
1844	37	68 ,,
1845	37	66 ,,
1846	30	62 ,,
1847	28	64 ,,
1848	28	64 ,,
1849	26	63 ,,
1850	27	62 ,,
1851	24	61 ,,
1852	19	60 ,,
1853	20	59 ,,
1854	22	55 ,,
1855	19	56 ,,
1856	23	56 ,,
1857	19	53 ,,
1858	15	52 ,,
1859	23	51 ,,
1860	24	52 ,,

From this statement it appears, that within the last sixteen years, the duty has fallen off 25 per cent., or from 68 millions, in 1844, to 52 millions, in 1860. That less interest is felt in the performance of the engines is also shown by the fact, that 50 engines were reported in 1841, but only 15 in 1858, and 24 in 1860, and of these latter numbers, many may fairly be supposed to be retained upon the list merely from habit.

If, however, the manner in which the duty-papers are made up be examined, with a view to determine the probable accuracy of this table, it will be found, that the data taken for that purpose are insufficient to give a fair comparison of the duty of the different engines, or of the same engines at different times, and that, although the duty has undoubtedly fallen off, it has not done so to the extent indicated by the monthly reports.

In the first place, the quality of the coal used is not taken into account in these papers, the duty being computed simply by comparing the weight of water lifted, with the quantity of coal consumed, without any reference to the capacity of the coal for producing heat; although it is well known, that the evaporative power of the different coals employed in Cornwall, varies considerably, and that the coal now in use is inferior to what it was twenty years ago. The reason of this is that when there was more competition as to the duty, every Engineer was anxious to employ only the best fuel. It is, of course, impossible to determine how much of the nominal decline in the duty may be assigned to this cause; but perhaps, an average of 6 millions, or 8 millions would be nearly the amount.

Again, it has been doubted whether many of the engines ever actually performed the high duty attributed to them. When a stronger rivalry existed, it is said, that unfair means were often resorted to, in order to place an engine in a high position. By some collusion between the Engineer and the Agent of the mine, the quantity of coal used in working an engine was sometimes made to appear less than was actually consumed. Engine-men at that period received 'duty-money,' and they were not remarkably scrupulous as to the means by which it was earned. The counters of some of the engines would perhaps register 18 inches, or 2 feet before the termination of the stroke, and the stroke was often shortened to that extent, of course with a diminished consumption of fuel; while in computing the duty, the engine was assumed to have performed its full stroke. A winding engine, perhaps on a Saturday afternoon, after ceasing to work, might be made to run several hundreds of revolutions without any load. But, although the duty of any particular engine might be thus temporarily increased, the average duty of the county cannot be considered as having been affected by these means, to any appreciable extent.

The practice of sinking the engine shaft, for the whole of its depth, or for a part of its depth, in a direction inclined or diagonal to the course of the lode, instead of perpendicularly, has increased of late years, and must have tended to diminish the nominal or reported duty of the engines; since the friction of the pit-work is considerably greater in an inclined shaft, than in a perpendicular one, especially when, as is often the case, the incli-

nation of the shaft varies at different stages of its depth, requiring an 'angle bob' at every turn.

In August 1841, of 53 engines reported, 27 drew their load perpendicularly; 22 drew perpendicularly from the surface to the intersection of the engine shaft with the lode, and below that point diagonally; and 4 drew diagonally from the surface. Of 24 engines reported in August 1860, 7 drew perpendicularly; 10 partly perpendicularly and partly diagonally; and 1 diagonally. Thus, in August 1841, 51 per cent. of the engines reported, drew perpendicularly; but in August 1860 only 28 per cent.

The increased depth of the mines, by adding to the dead weight and friction of the pit-work, and of the water in the pumps, must also have tended to lower the nominal or reported duty. In August 1841, the average length of the lifts attached to each engine was 144 fathoms 4 feet; in August 1860 it was 173 fathoms 3 feet.

Formerly, the practice of working expansively was carried to a greater extent than it is now. The use of high steam, cut off at an early part of the stroke, was also carried farther than was compatible with safety, involving repeated breakages of the main-rod, the piston-rod, and other principal parts of the engine; until experience showed, that a less expansion, and a more gradual starting of the ponderous machinery, though giving a lower duty, was nevertheless cheaper and safer in the end. Sims' combined, or double-cylinder engines, were designed in order to obtain a greater expansion than could be safely employed in the single-cylinder engine; but however perfect in theory, the advantages arising from the increased expansion seem to have been more than counterbalanced by the greater friction and waste of the two cylinders, and by the enhanced cost, &c.; therefore few of them are erected at present.

But, after allowing for all these legitimate causes of the lessened nominal duty, there can be no doubt, that the average duty actually performed by the Cornish engines is at present far below what it should be; to the extent (on the authority of Mr. W. Browne, before referred to) of at least 10 millions. The primary cause of this decline seems to be, the indifference of mine proprietors as to the performance of the engines. When legitimate mining was less rare than it is at present, and when more mines were held by men who intended to work them, economy of fuel was carefully attended to, and the managers were, in a great measure, guided in their choice of an Engineer, by the duty attained by his engines. Now, however, that so many mining operations are undertaken merely for the purpose of speculating in shares, the performance of the engines is regarded as a matter of secondary importance. Even in those mines of old standing, which are so worked as to

yield dividends, both agents and proprietors seem to be indifferent to the performance of the engines. The excessive desire for a high duty, which prevailed a few years ago, has, in fact, been followed by a reaction. So many accidents, any one of which perhaps cost more than could be saved in fuel in the course of years, attended the use of high steam cut off at an early part of the stroke, that such accidents came almost to be considered as inseparable from the attainment of a high duty, and economy of coal was regarded as synonymous with repeated breakages. It is, however, quite possible to raise the duty considerably above the present average, without resorting to an undue rate of expansion. The principal thing which appears to be required for the attainment of this object is, in the Author's opinion, a more perfect and extended system of reporting the engines; the present system, although the high duty of the Cornish engines is undoubtedly owing to its adoption, being, in many respects, defective. For instance, the duty of the engines is estimated by merely comparing the weight of water raised, with the quantity of coal consumed. This mode of computation leads to most erroneous results, since, as has been already mentioned, not only does the quality of the coal used vary considerably; but a still greater error arises from the omission of any allowance for the friction and inertia of the horizontal rods attached to some of the engines, for the 'angle bobs' and diagonal rods in the shaft, and for the number of lifts through which the water is raised. It is true, that a notice of the flat rods, &c., attached to each engine is inserted in the duty-paper, but no corresponding deduction is made from the coal consumed; so that an engine which draws its load from one shaft perpendicularly, in which case the friction of the pit-work is of course a minimum, is put down as doing as much work as another which raises an equal quantity of water, distributed among four shafts, or five shafts, each perhaps 80 fathoms, or 100 fathoms distant from the engine; whereas, from the power absorbed in giving motion to the flat rods, and from the increased friction of the pit-work, the duty actually done in the latter case is much greater than in the former. Again, no classification of the engines is adopted, to distinguish those from which a good duty might be reasonably expected, from those of much lower pretensions. Thus a pumping-engine with a cylinder 80 inches or 90 inches in diameter, in which the steam is cut off at one-fourth or one-fifth of the stroke, and in which every care is taken to prevent loss of heat by radiation, is put in the same list with a rotary engine, the cylinder of which is 12 inches or 14 inches in diameter, working with a slide-valve, and having the steam-pipes and cylinder exposed to the atmosphere. The omission of any notice of the rate of expansion at which an engine works, and of the

vacuum, is also a serious defect, since it is impossible, by a mere inspection of the duty-paper, to tell how far the high duty attained by one engine may be attributed to the use of high steam cut off at an early part of the stroke; or how far the lower duty attained by another, may be owing to the circumstance of some weak part of the pit-work, or of the flat rods connected with the engine, rendering it unsafe to work at a high degree of expansion. This omission is, in fact, an inducement to an Engineer who wishes his engine to stand high upon the duty-paper, to expand the steam as much as possible, even to a dangerous extent.

The Author begs, therefore, to submit to the Institution a form of duty-paper differing in several respects from that now published. In the first place, the load upon the piston is taken from an indicator diagram, and from the load thus ascertained the duty is computed; the difference between the load upon the piston, and the weight of water actually lifted, that is, the loss by the friction of the pit-work, &c., being placed in a separate column. Secondly, the part of the stroke at which the steam is cut off, as well as the vacuum attained, are stated opposite each engine. Thirdly, a notice of the quality of the coal used, as far as it can be ascertained, is added. And lastly, the engines are divided into two classes, those which may be reasonably expected to give a good duty, and those which, from length of service, or from their small size, or from other causes, cannot fairly compete with the former. —(*See Table*, pp. 52 *and* 53.)

The advantages expected to be derived from this form of report are as follows:—First, by taking the load upon the piston from an indicator diagram, means are afforded for making a fair estimate of the work actually done by the engine, while by placing, in a separate column, the difference between the load upon the piston, and the weight of water actually lifted, encouragement is offered to improvement in the construction and fixing of the pit-work. Secondly, the columns containing the notice of the degree of expansion employed, and the vacuum produced, are not only useful for reference, but, by serving to show how far the duty performed may be attributed to the rate of expansion, are also useful to check the practice of carrying expansion to an undue extent. Thirdly, by noticing the quality of the coal consumed, the duty of the engine can be more accurately estimated. And, lastly, the classification of the engines tends to excite competition, by showing, at a glance, the comparative merits of those engines which might fairly be expected to perform an equal duty. It is, however, useless to suggest any improvements in the manner of reporting the engines, unless some effort be also made to obtain an increase in the number of engines reported. At present scarcely more than one-tenth of the engines at work in Devon and Corn-

wall appear in the monthly record, and very little interest is taken in the publication of the duty-papers. If mine proprietors would heartily co-operate in supporting a duty-paper similar to the one now proposed, there can be little doubt, that the result would be a rapid and marked improvement in the duty performed, and that the saving in the consumption of coal would repay a hundredfold the cost of publication. In fact, Cornish engines are now capable of doing a much higher duty than was realised twenty years ago ; the workmanship is improved ; and, unlike other stationary engines, or marine engines, which admit of an almost endless variety of form, very little variation will be found in their general design, though a few modifications have been introduced in some of the details, as the hand-gear, &c., more with a view to the appearance of the engine rather than to its useful effect. But, independently of the saving of fuel, as vast improvements have been effected in all other departments of engineering, so, for the credit of the county, every effort should be made, not only to maintain the high position, but to increase and develope the powers of the Cornish engine.

CLASS A.—

MINES, and Parish in which situate.	Time.	Engines.	Stroke in the Cylinder.	Stroke in the Pumps.	Number and Description of Lifts.	Length of the Lifts.	Diameter of Plunger, &c.	Water Way in the Clack.	Diameter of Pumps in the Column.	Length of Flat Rods, &c.	Load in Pounds (weight of Water lifted).
			Feet.	Feet.		Fms. ft.	in.	in.	in.	Fms.	
WEST WHEAL SETON (Camborne).	Aug. 8 to Sept. 11	Harvey's 85-inches, single, 378 H.P.	11·75	9·75	1*p* 1*p* 1*p* 1*p* 1*p* 1*d* 1*d*	26 1 30 0 35 5 26 4 31 2 12 4 13 3	12 14 14 11 11 11 11				54914
ALFRED CONSOLS (Phillack).	Aug. 21 to Sept. 21	Davey's 80-inches, single. 335 H.P.	10·0	10·0	1*p* 1*p* 1*p* 1*p*	41 2 34 5 16 4 30 4	16 16 16 8	13½ 13½ 16 8	16 16 16 7		54586
CARGOLL MINES (Newlyn).	Aug. 22 to Sept. 18	70-inches, single, 256 H.P.	9·75	9·75	1*p* 1*p* 1*p* 1*p* 1*d* 1*d* 1*p* 1*d*	22 0 34 0 33 1 33 0 11 4 11 3 11 5 11 5	13 16 14 8 14⅛ 9 16⅛ 16	13⅜ 14½ 13½ 9 17 9½ 14 15	12 14 14 10 15 10 17 17		62162

CLASS B.—ENGINES from which

BOTALLACK (St. Just).	Aug. 15 to Sept. 8	30-inches. single, 47 H.P.	6·33	5·5	1*p* 1*p* 1*p* 1*p* 1*p* 1*p*	53 0 43 0 33 0 53 0 23 0 18 0	7½ 6 5½ 5¼ 5¼ 4⅝	7 6 7 6 5½ ..	7 7 6½ 6½ 6 6		16373
WHEAL KITTY (Lelant).	Aug. 11 to Sept. 22	33-inches, single, 57 H.P.	6·0	6·0	1*d* 1*p* 1*p* 1*p* 1*p* 1*p* 1*d* 1*d* 1*d*	2 0 27 0 38 1 32 0 34 0 31 0 11 0 11 0 10 0	6½ 5½ 5½ 5½ 5½ 5 4½ 4½ 4½	4½ 5 5½ 5½ 5 5 5 5 5	5 6 6 6 6 5 5 5 5		11020
GONAMENA (St. Cleer).	Aug. 17 to Sept. 19	22-inches, double, 50 H.P.	5·0	6·0	1*p* 1*p* 1*p*	21 0 49 2 37 0	8 6 6	7¾ 7¾ 6	8 6 6	17	9102

* These columns are new. † These columns are similar to columns 15, 17, and 18 in Lean's Paper,

First-Class Engines.

Number of Strokes, and Strokes per Minute.	Load on Square Inch of Piston, as per Indicator.	Load on Square Inch, as per Water lifted.	Difference, showing Power absorbed by the Pit-work.	Actual H.P. employed, as per Indicator.	Consumption of Coal in cwts.	Consumption of Coal per H.P. hourly.	Duty, the Load being taken by the Indicator.	Part of the Stroke at which the Steam is cut off.	Vacuum.	Remarks on the Quality of the Coal used.	Average Quantity of Water drawn per Minute.	Oil and Tallow consumed per Week.	Remarks, &c.
	*		*	†		†	†	*	*	*			
											Gals.		
130000 2·6		8·0			1179						169		Drawing 43 fathoms perpendicularly, &c.
194000 4·3		10·8			1625						374	2 qts. 20lbs.	Spring Piston. Drawing perpendicularly, &c.
207000 5·2		16·1			2366						441	6½ qts. 28lbs.	Packed Piston. Drawing perpendicularly, &c.

a High Duty cannot be expected.

115000 3·2		20·1			229						21	½ qt. 20lbs.	Packed Piston. Drawing 53 fathoms, &c.
195000 3·2		12·8									19	1 qt. 12lbs.	Spring Piston. Drawing 90 fathoms perpendicularly, &c.
499000 10·4		4·7			402								Packed Spring Piston. A rotary engine, &c.

except that the indicator diagram is taken as the basis of calculation, instead of the load lifted.

Mr. F. J. Bramwell said, the Paper, as he understood it, was more addressed to the question of the falling-off in the performances of the Cornish pumping engine, as a mere fact, and to propositions for obtaining in a better form the returns of the duties of those engines, than it was to engineering subjects, properly so called. The Paper entered into no engineering details beyond accounting for the falling-off in the duty, by the assumption, that more mining than formerly was now done by following the direction of the lode, and that thus, in many cases, inclined shafts were to be found in lieu of perpendicular shafts, and from that cause, viz., the extra friction of pumping in inclined shafts, engines gave less apparent duty, so that the duty actually performed was more than that with which the engines were credited in the returns.

Notwithstanding this was his view of the scope of the Paper, he apprehended it was open to him to offer some general remarks upon the Cornish pumping engine, though those remarks might not strictly arise out of a Paper having no greater extent than the one under discussion.

But, before proceeding to those general remarks, he would address himself to the statement, that the duty, which averaged in 1841 65 millions had fallen, at the present time, to from 44 millions to 52 millions, or a mean of 48 millions, and the Author expressed his entire belief in the fact of this diminution. Now 48 millions of duty represented a consumption of from $4\frac{1}{2}$ lbs. to $4\frac{3}{4}$ lbs. of coal per hour, and per H.P. of 33,000 lbs. raised 1 foot high.

It was difficult to resist entertaining the impression, that when the performance of an engine was expressed in figures of millions, and not in pounds of coal per indicated H.P., it was, even to Engineers, like hearing of a matter in a foreign language, which they did not take the pains to translate; and in that way an exaggerated idea of the wonderful economy of the Cornish engine had been created. For instance, taking 67 millions as the maximum average duty referred to in the Paper, that gave, when translated, $3\frac{1}{4}$ lbs. to $3\frac{1}{2}$ lbs. of coal per indicated H.P., and with a duty of 44 millions only, the consumption was as high as from $4\frac{1}{2}$ lbs. to $4\frac{3}{4}$ lbs. per indicated H.P.

Having thus briefly noticed the value of millions of duty when converted into the more familiar terms of consumption per H.P., he would now consider the proposed plan for calling attention to the proper performance of the engines, and for inducing the owners of mines to work those engines in a more economical manner. The Author suggested, in the first place, that particular attention should be paid to the quality of the fuel. No doubt that was a very proper suggestion, because if no more precise description than the general term 'coal' were given, it was obvious how useless,

for any purposes of comparison of efficiency of different engines, must be the results obtained from such vague data.

The next proposal, as to the taking and recording of indicator diagrams, he thought most desirable, if it could be practically carried out; but there was a difficulty which he would state presently.

The existing plan, in taking account of the work done, recorded the number of strokes made, and treated them, of course, as full strokes; but, according to the Paper, instances had occurred where engines worked upon a short stroke, and received credit for a long one. If, however, the full stroke really was made, and the number of such strokes was registered, and the amount of water and the height lifted were given, no doubt a very good statement of the work done was afforded, subject, of course, to the question of friction in shafts. But if an indicator diagram were taken as the test, it was easy to have an indicator diagram that should give a result far better than the average; and it might, in fact, with every desire to do right, be difficult, without multiplying the indicating to a greater extent than most persons were inclined to do, to get a really fair average diagram. He thought it right to point out those difficulties, but, nevertheless, indicator diagrams contained information so useful, that he felt the suggestion of the Author was one well worthy of consideration.

The next proposition was, that the amount of expansion should be stated, not, as was generally the case, with the view of awarding praise to those who worked with much expansion, but rather with the object of censure; as he inferred from the Paper that the Author looked upon economy obtained by expansion as an economy obtained by false and artificial means; from which an admission might be gathered, that in the former time, when the engines performed the high duty, the falling off in which was now lamented, an amount of expansion was employed that involved breakages which rendered the economy very questionable in a commercial view; and it was for this reason, probably, the Author looked upon expansion as a bad thing *per se*.

The Author appeared to have omitted from his suggestion for an improved return, an important point, and that was, the means of ascertaining how far economy, or non-economy was due to the engine, and how far it was due to the boiler. No doubt it was the fact, that if the amount of coal burned per hour, and the quantity of water raised per hour, were known, that knowledge was enough for the commercial question. But such concise information was not enough, looking at the question in a scientific point of view, because then it became necessary not merely to know the beginning and the end, but also the intermediate steps, that it might be seen in what direction amendment should be looked for. He therefore thought the improved form of returns should give

the amount of grate surface, the extent of heating surface, and the weight of coal burnt per foot of grate surface per hour, as well as the quantity of water evaporated, as ascertained by means of a water meter.

These few remarks he had offered upon that which he considered to be strictly the subject of the Paper; what he had further to say would perhaps be beyond that strict subject, although not beyond the subject of pumping engines in general.

No doubt Engineers owed a great deal to the Cornish engine. He believed to that engine was due the continuance in the use of the steam jacket after it had been practically abandoned elsewhere, and after Tredgold, in his work on the steam engine, had condemned it. Whether the Cornish Engineers who continued to use the jacket did so because they had examined into the theory on which its advantages were based, or whether they simply continued to use it from the experience they had acquired of the good that it did, he could not say. But whichever way that might be, the propriety of continuing the use of the jacket was now confirmed by the fact, that the employment of expansion and steam jackets was the rule in all the best engines. Also to Cornish Engineers was due the elegant contrivance of the lantern brass, by means of which the leakage of air through the stuffing box into the cylinder was prevented, and thus a high vacuum could be maintained, which was of course most important. The double-beat valve as applied to pumps, originated from those engines; and though there had been instances in which the principle of those valves had been lost sight of, and harm had been done by their use, yet the double-beat valve, when properly applied to pumps, had been highly beneficial. But, having made these most deserved acknowledgments to Cornish Engineers, he felt compelled to go on and express his opinion, that it would be a waste of time ever to seek to get the utmost effect out of fuel by the employment of the Cornish engine. He believed no alteration of the forms of the returns, and no care in the management of the engines, would give so high an effect from fuel with a Cornish engine, as could be obtained consistently with safety, with engines of another class.

In his opinion, the most beneficial use of a Cornish engine would be in a mine; because there, at all events, there was an uniform height to which to raise the water; consequently, when by the power of the steam, the weight of the rods was lifted, those rods, in going down again, encountered an uniform resistance, and thus there was always a regular load for the engine to work against, and in that way a mine was a suitable place for a Cornish engine. But when the Cornish engine was used to pump the supply of water to a town, he could not help thinking, that unless the pumping were done into a reservoir, in which case there was a constant resistance,

that kind of engine was the least calculated to do the work required; because the steam being used to lift the weight, and the weight to lift the water, the height which formed the resistance to that weight should be uniform. But in the distribution of water, in the many cases in which it was pumped directly into the mains, the pressure in those mains would not be uniform.

Some years ago he was engaged, under one of the oldest Members of the Institution, in altering a pumping-engine of the old Boulton and Watt class, at a waterworks near London, into a Cornish engine; and to enable that to be done, a stand-pipe 210 feet high was fixed, and thus a constant load to pump against was obtained on the engine side of the stand-pipe. But one of the Directors had the curiosity to see what the pressure was on the other side of the stand-pipe, and, on a gauge being applied, it was ascertained to be sometimes only 140 feet, or 150 feet, while the water was raised always to the 210 feet, so as to flow over the stand-pipe. Thus it was clear, that at all times when the pressure required to drive the water was only 140 feet, or 150 feet head, the economy of the engine must have been great indeed to have made it worth while to raise water by it, to 210 feet, when from 140 feet to 150 feet would have sufficed. That, he thought, was a fair illustration of the unsuitableness of those engines, except when the necessary work to be done involved the use of a perfectly equal load.

Then came the question of the cost of those engines. That was the commercial part of the subject. It was an old proverb that gold might be bought too dear; and he would apply that proverb to the consideration of the question of the relation between the cost and the effective performance of those engines. In the first place, with the exception of Sims's engine which was not much in use, although it deserved great credit, Cornish engines were single acting. In Sims's modification there was a double cylinder of peculiar construction. The high-pressure cylinder was put upon the top of the low pressure cylinder, and there was at all times a communication between the under side of the small cylinder piston and the upper side of the large one. The steam, after it had driven down the small piston, expanded under the large piston, and raised it; and in that way, and in that sense, Sims's engine was double acting. But omitting Sims's engine, and speaking of the Cornish engine proper, the latter was single-acting. It was clear, that the size and strength of the parts of an engine, and the size of the engine-house and foundations would be the same, whether the engine was doing the work of a single-acting, or of a double-acting engine; but if single-acting, only half the work was obtained for the same first cost, that would be obtained if the engine were double-acting. That was a strong reason for discarding that class

of engines, unless it were shown that such an economy was obtained as could not be obtained from any other class; but, so far from being able to show, that the superiority in economy must of necessity be with the Cornish engine, he thought, it was easy to prove, that there was less economy from those engines with safety, than from those of another class. And as regarded relative cost, he would cite the instance of a 100-inch cylinder Cornish engine, then in action at a waterworks in the neighbourhood of London, the cost of which, he believed, with pumps, engine-house, and boilers, was about £23,000. He believed the work it did was only 250 theoretical H.P. of 33,000 lbs. raised 1 foot per minute. He thought that must be admitted to be a large outlay, having regard to the work performed. This was an item on the debit side of the question, against the use of the Cornish engine.

He would now endeavour to look at that which must constitute the credit side of the question, viz., the economy, and he thought it would be found, that the details of the working were not favourable for obtaining economy. That engine made a 10-feet stroke in ordinary work; when cutting off at $\frac{1}{4}$ of the stroke, it was stated this 10-feet stroke was made in a second of time, or at the rate of 600 feet per minute. The average pressure on the piston to raise the load was about $16\frac{1}{2}$ lbs. per inch, but the pressure at the moment of cutting off the steam was $2\frac{1}{2}$ times that which was required to balance the load. That excess of pressure over the load would cause it to move with $2\frac{1}{2}$ times the rapidity due to gravity, or to pass through $2\frac{1}{2}$ feet in a $\frac{1}{4}$ of a second of time. With that great rapidity, of course there must be a large size of suction valve, to get the water into the pump in a sufficiently short time, and if higher expansion than a $\frac{1}{4}$ were attempted, the initial velocity would be increased to a greater extent, and the difficulty in the size of the valves, of which he had spoken, would be proportionably augmented. Although he had said, that the stroke of the piston was made at the rate of 600 feet per minute, the engine was not making more than 10 double strokes per minute; and that, at a 10-feet stroke, gave only 200 feet per minute of the piston, though 600 feet was the rate at which it worked when water was coming into the pumps. Had that engine been a crank engine, working at 10 revolutions per minute, $\frac{3}{4}$ of a second would be allowed for getting through the first foot and a half of the stroke; while, in the Cornish engine, the whole 10-feet stroke was made in one second, and it was fair to presume that about 6 feet, or 7 feet were done in $\frac{3}{4}$ of a second. He thought, that a consideration of the great speed of the piston of the Cornish engine would lead to the conclusion, that really high expansion could not be safely employed. There were numerous instances of engines working with cranks, where the expansion

was carried to a far higher degree than 4 times, and where correspondingly satisfactory results in economy had been obtained. It might be assumed, that the Cornish engine he had spoken of, being under the supervision of a most experienced Engineer, was worked as economically as was found to be practicable; looking, on the one hand, at the high initial pressure necessary to obtain great effect from expansion, and on the other hand, at the danger of accident from the great velocity due to such high pressure. The performance of that engine, compelled to work at an expansion of only $\frac{1}{4}$th, therefore, clearly showed, that Cornish engines generally were far from being economical, and that their capabilities were far less than those of engines of another class.

There was another point in reference to the question of economy. As those engines had no power of stopping themselves at the end of the stroke without striking blocks, there was a margin obliged to be left in the cylinder. In those engines, $3\frac{1}{2}$ per cent. was the margin for the length of the stroke; and cutting off at a $\frac{1}{4}$, this clearance was equal to 14 per cent. of the whole amount of steam let in. Comparing the Cornish engine with others, it should be borne in mind that, as a rule, it was working much below what it could do as a maximum; and, therefore, it was getting an advantage arising from the extremely slow combustion. Lean's Reporter showed the weight and number of boilers employed for each engine, and assuming ordinary proportions of grate bar to be applied to those boilers, then there had not been a consumption of more than 4 lbs. of coal, per square foot of grate surface per hour, whilst in a marine engine, from 20 lbs. to 28 lbs. were consumed, or rather destroyed, in the same time. If then, there was economy in slow combustion, that economy was put to the credit of the Cornish engine, while, in truth, it was due to the mode of evaporation. He might state that in August last, when in Liverpool, he saw a Cornish pumping engine which was using so many boilers as to be burning off only 4 lbs. of coal per foot of grate surface per hour. In the same month, he was engaged in taking the particulars of one of the vessels of the General Steam Navigation Company, and he found, that 28 lbs. of coal per foot of grate surface per hour were burnt, or perhaps more properly, he should use the words distilled off, because he had found, on making air holes through the smoke-box, that it was full of unconsumed gases, which on being, by means of these holes, supplied with air, took fire. No doubt therefore, had the pumping engine at Liverpool been of the identical construction of the marine engine to which he had alluded, that pumping engine would have shown a higher rate of duty at Liverpool than on board the steam-boat; but that would clearly have been an economy due to the slow rate of combustion, and not to the engine itself.

Touching the comparison between the duty of the Cornish engine in its best days, and that of other engines, he was informed, that at the Royal Agricultural Show, held at Chester, there was exhibited an agricultural engine which produced an indicated H.P. of 33,000 lbs. raised 1 foot high for a consumption of $3\frac{1}{2}$ lbs. of coal per hour. The H.P. was ascertained by the break. It would be found, that such a result was equal to about 60 millions of duty. That showed, that in a mere agricultural engine, a duty had been obtained equal to that which was performed in the best days of the Cornish engines. It would be recollected, that some years ago a Paper was read upon the Ether Engines of Du Trembley,[1] when it was shown, that steam-boats worked at as low a consumption as $2\frac{1}{4}$ lbs. of coal per H.P. per hour, which was nearly equal to 100 millions of duty. He was not advocating the use of ether engines; but the result of their performance was an interesting one, and based on something considerably more than a mere solitary experiment. He could refer to instances of double cylinder engines working at 3 lbs. of coal per indicated H.P. per hour, thus giving 70 millions of duty. He therefore trusted he had shown—first, that the Cornish engine was an expensive machine for the work it did, and secondly, that it was an engine which could not be improved so as to make it equal to machines of another class. He therefore thought the use of Cornish engines ought not to be extended for waterworks pumping purposes, nor even for the special purposes for which those engines were the most applicable, viz., the unwatering of mines, as better could be used. He was aware of the peculiarity possessed by those engines, of varying in their work from a minimum of one stroke up to a maximum of ten strokes, or twelve strokes per minute; and consequently, that if after having put up one of those engines, an influx of water into a mine took place, there was a range of working power which no other engine possessed. But he believed, taking into consideration the money required to erect an engine possessing a maximum power sufficient for such a contingency, but which engine would not, in ordinary work, exercise more than about one-fourth of that power, it would be more advantageous to expend the same sum of money in providing two, or more engines of a different construction, and to use one such engine up to its proper power for the ordinary duties of the mine, and the other along with the first when required by any emergency. It would be more economical, and there would be the advantage of duplicate machines in case of accident, instead of there being only one engine to rely on. He was of this opinion, even bearing in mind the great distance of the engine from the work to be done, because whatever was the distance of the work, it had to be done by re-

[1] *Vide* Minutes of Proceedings Inst. C. E., vol. xviii. p. 233.

ciprocation of rods; and he would much rather that the rods should be put into motion, and be brought to rest gradually, by a crank action, than that they should be started from rest in the violent manner of a Cornish engine.

Mr. E. A. COWPER thought a more interesting subject could not be brought before the Institution, for he might state, with confidence, that although there might now be less interest taken in engines in Cornwall than there was some years since, more attention than ever was being given to the economical working of engines for waterworks, marine, and stationary purposes generally, throughout the country.

He could not but think, that in many respects the Cornish engine was unsuited for waterworks pumping purposes, and he would give his reasons for that opinion. It had been remarked in the Paper, that in Cornwall those engines were not now worked so expansively, or with such high steam as formerly, and if it were so, it was no doubt one of the causes of the falling off in duty. Whether the Author contemplated lessening expansion to a great extent he could not say, but if so, a more uneconomical proposition could not be made. If economical working was sought for, an engine must be made to work in such a manner as to obtain all the power that the steam was capable of exerting, according to laws now ascertained, and that could only be done, by taking large advantage of the pressure exerted by steam during expansion.

The question was, how to arrange an engine so as to take full advantage of expansion, without producing an objectionable variation in the power exerted at different parts of the stroke. The evils of great variation of pressure were so well known to those Engineers who were intimately conversant with steam engines, that it was hardly necessary to refer to the facts alluded to by the Author, such as "the repeated breakages of the main-rod, the piston-rod, and the other principal parts of the engine," and which accidents he stated "attended the use of high steam, cut off at an early part of the stroke, so that economy of fuel came to be regarded as synonymous with repeated breakages."

Then with regard to the actual number of strokes, or discharges of water, which the Cornish engine would make per minute, working with single action, under many circumstances it would produce a most prejudicial irregularity in the flow of the water, in a main 8 miles or 10 miles long. The flow of the water must be sufficiently regular, or there would be great risk of bursting the mains.

But with a pair of crank engines, the cranks being at right angles, there were four discharges of water in one revolution, and as there were nearly twice as many revolutions per minute as there were strokes of the Cornish engine, it followed, that there were

nearly eight discharges of water by the pair of crank engines, to the one discharge by the Cornish. Besides which, there was a considerable interval when the Cornish did not discharge any water, while on the other hand the pair of crank engines gave nearly a regular flow of water through long mains, with only a very small air vessel.

In the next place, as to the nature of the work which Cornish engines had to perform when pumping from deep mines; it must be borne in mind, that that work was very different from pumping for waterworks purposes, as the weight for the steam to act against, when first let into the cylinder was very great, owing to the length and number of pump rods, plungers, levers, and 'balance bobs,' to support the weight of the rods, so that not only the weight of the rods (which was often more than the engine could lift), but also other weights had to be put in motion at the ends of the 'balance bobs.'

Thus there was an immense accumulation of weights (often several hundred tons) to be set in motion by the first impulse of the steam; and it was the vis inertiæ of that mass that permitted the use of a total pressure of steam on the piston equal to far more than the load, and it was of course the momentum of that mass that continued the motion of the piston, when the pressure of the steam on the piston had, by expansion, fallen far below the load. But Cornish engines in waterworks were only arranged to put in motion a certain weight, viz., a weight equal to the load, perhaps about forty tons or fifty tons; and therefore it frequently happened, that although there was a pressure of 40 lbs. of steam in the boiler, there was only a pressure of about 12 lbs. in the cylinder, and consequently the steam could not be cut off as early as when there was much more weight to be put in motion. Thus such engines could not work as expansively, and therefore not as advantageously, as regular Cornish engines when pumping from deep mines. If very heavy beams were made, or rather, long beams with heavy weights at each end, the engines would then have more vis inertiæ and momentum to work on, and 40 lbs. steam could be put into the cylinder and be expanded largely; but, as before stated, this was not commonly done.

He was aware that Engineers of experience in waterworks pumping-engines thought it so objectionable to have a great variation in the pressure on the piston, in one stroke, that they would not cut off the steam earlier than about $\frac{1}{3}$rd of the stroke; and though they certainly obtained good and steady work from such practice, it needed hardly to be pointed out, that if any reasonably high pressure of steam was so used, the pressure at which the expanded steam would escape into the condenser would be considerable. Therefore rather low steam was often used in

such cases, and great expansion and economy were given up. Mr. Cowper had himself cut off high-pressure steam at $\frac{1}{9}$th and even $\frac{1}{11}$th, and had expanded it in one cylinder in a crank engine; but the result had been an unpleasant variation of pressure, so as to cause him to make the cutting off later.

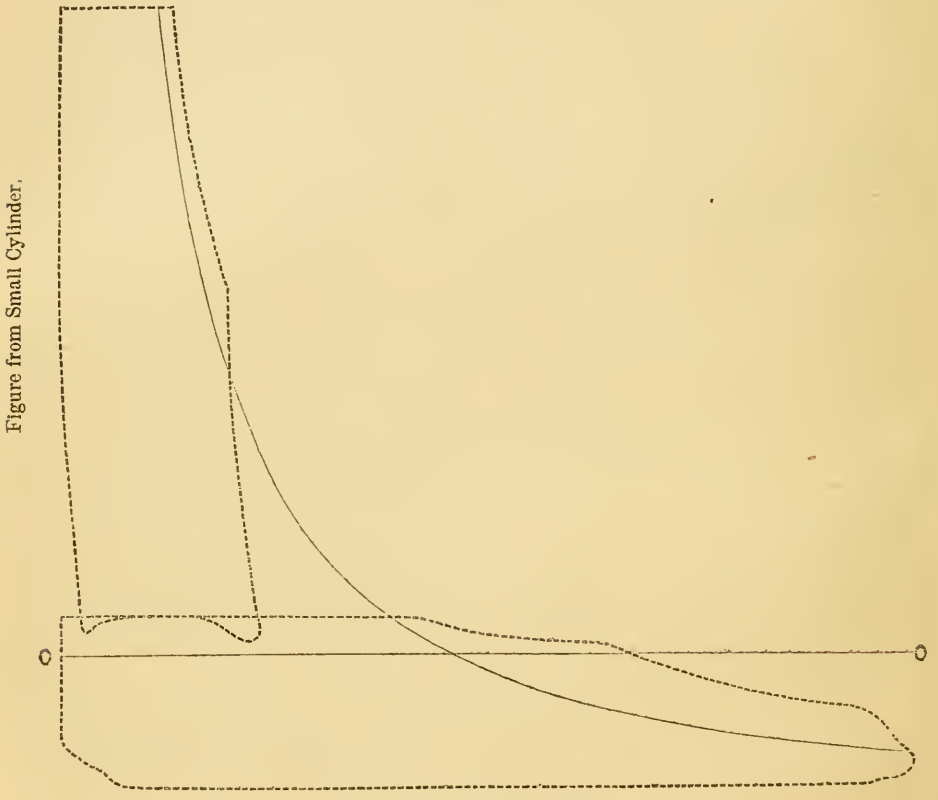
It had been clearly shown by Mr. Pole, in an excellent Paper, that if a pair of double-cylinder crank engines were used, and the steam was expanded first in one cylinder and then in another, that the result would be a moderate expansion in each cylinder, but great expansion on the whole, and yet with only a moderate variation in pressure throughout the stroke, though at the cost of an expensive and rather complicated pair of engines, involving the use of four cylinders.

He thought the problem to be worked out was, moderate variation of pressure throughout the stroke, and great expansion, in engines of simple and inexpensive construction. He believed that problem might be solved in a simple manner; in fact the solution had been arrived at, and the result was satisfactory in actual practical working. By the application of steam-jacketing in an extended manner (which he had long and constantly urged upon marine Engineers), it was possible to work with perfect efficiency two such cylinders as constituted an ordinary double-cylinder engine, on two cranks at right angles to each other, that was, to form a pair of engines in place of one engine, and it was done in the following manner:—A steam-jacketed reservoir was formed for the reception of the steam as it came out of the first, or high-pressure cylinder; and it was so arranged with a sheet-iron lining inside, that the steam on entering did not come into extensive contact with the steam-jacketed sides of the reservoir, and thus lead to an increase of "back-pressure;" but on the steam passing out of the reservoir (after the cranks had travelled 90°), the steam then came into contact with the sides of the reservoir, and had the full benefit of the steam-jackets in helping to keep up the temperature more nearly to that of the boiler. Thus the steam could be cut off at any point in each cylinder, the total expansion being the multiple of the number of times it was expanded in each cylinder, so that if it was cut off at half stroke (producing great regularity of pressure throughout the stroke), it would be expanded four times, or again, with the same cut off, it might be expanded eight or nine times, or more, if a slight loss were allowed to take place in the dropping of pressure on the entrance of the steam into the reservoir.

Fig. 1 showed two indicator diagrams from an actual engine, both drawn to one scale, so as to be in just proportion to each other. It would be seen, that the loss of power by the drop in pressure on the steam entering the reservoir was more than com-

pensated by the effect of the steam-jacketing carried throughout the cylinders, cylinder-covers, and reservoir: the total expansion was, in this case, 8·82 times.

Fig. 1.



Note.—The large cylinder has 4·41 times the capacity of the small cylinder; and when the steam is cut off at half stroke in the small cylinder, it will be expanded 8·82 times.

In this pair of engines the power was exactly the same, and the cranks, connecting-rods, piston-rods, &c., were also similar, up to the stuffing-boxes, and the only difference between the engines was, that one cylinder was larger than the other. There were no expansion valves, as each engine had its own working slide, which cut off at half-stroke, and gave the indicator diagrams shown in Fig. 1. Thus the engines were of the simplest possible construction.

By a proper adjustment of the exact points of 'cut-off,' viz., a little before and a little after the half-stroke, the greatest possible uniformity in rotative power might be obtained. But this was not exactly what was wanted in pumping engines, which had a nearly uniform resistance throughout the stroke, and should therefore have as little expansion in each cylinder as was compatible with great total expansion and economy. Pumping engines and fac-

tory engines had been made on this plan, and were working admirably.

Mr. Fleeming Jenkin said, although less interesting than the details which had just been mentioned, a comparison between the actual duty recorded for these Cornish engines, and the duty calculated simply from the dynamic theory of heat, might not be wholly uninteresting. It was well known, that 772 foot lbs. of work must be consumed to give a unit of heat, and that conversely, when applied to produce work, one unit of heat would be annihilated in order to produce 772 foot lbs. of work—a unit of heat being the quantity required to raise 1 lb. of water one degree Fahrenheit. It was, however, not so generally known, that the percentage of the whole amount of heat, actually and theoretically convertible into work, depended not only on the quantity of heat supplied, but also on the difference of the temperatures at which the heat was supplied and withdrawn; that was to say, on the difference between the temperature at which the body performing the work (steam for instance) was supplied, and that at which it was withdrawn. Those elements were sufficient for the calculation, whatever the body performing the work might be. If the difference between the temperature of entrance and exit was great, a large proportion of the whole heat might be converted into mechanical effect; if small, but little could be so converted.

There was an analogy between this, and the water engine in an ordinary mill. The power obtained from the water wheel not only depended upon the quantity of water, but also upon the fall. In like manner, the power from any heat engine did not depend upon the quantity of heat only, but upon the fall. The analogy was not perfect, inasmuch as in heat engines a certain quantity of heat entirely disappeared, whereas in a water engine there remained all the water at the lower level, as well as at the higher.

To calculate the power of the steam engine by this method, or rather to calculate the maximum power to be obtained from a given engine, three things were required to be known, viz., the quantity of heat, the temperature at which it was supplied, and that at which it was withdrawn. Those were data which had hitherto been much neglected. Still if, as was sometimes the case, the total quantity of water evaporated was known, and the pressure in the boiler, the total heat supplied could be calculated from those data. The temperature of the steam in the boiler must be taken as the temperature at which heat was supplied, provided the object was to compare the actual duty with the maximum duty possible under the circumstances; that was known. But if the object was to compare the real effect, as shown by an indicator diagram, with the calculation by the theory of heat, the temperature of the steam entering the cylinder would have to be taken instead; and that

was seldom observed. The temperature at which the steam was withdrawn was that of the condenser. This too was seldom observed, but could be calculated, when the back pressure was known.

Taking the example of the Fowey Consols engine, he found 125 millions recorded as a maximum duty for twenty-four hours. Shortly after, the total amount of water evaporated by 1 lb. of coal was found to be $10\frac{1}{4}$ lbs., with a pressure of 55 lbs. in the boiler, corresponding to a temperature of 284°. Taking the temperature of the condenser at 86° Fahr., he found the total theoretical duty of that engine, calculated from the amount of heat, would be 223 millions, while the actual duty was 125 millions, or only about 56 per cent. But it was probably unfair to take the temperature of exit as that of the hot well. If a back pressure of $2\frac{1}{4}$ lbs. were allowed, and a temperature corresponding to that pressure of steam was taken into account, the total theoretical duty would be only 170 millions. The duty obtained was 125 millions, and in that amount the back pressure was not included; consequently, on that occasion, the engine, it might be assumed, did obtain the full maximum duty which could be obtained from the heat supplied to it. This conclusion was confirmed by the fact, that the duty recorded corresponded with $1\frac{3}{4}$ lb. of coal, per indicated H.P.; and in engines cut off at a $\frac{1}{4}$ stroke, that was probably the utmost that could be obtained.

Hence he drew the conclusion, that where these engines were so well worked, that the utmost possible amount of effect for the heat supplied was really obtained from them, only about a fourth or fifth of the heat supplied was, by these engines, converted into mechanical effect. Whereas if an engine could be practically constructed, which would work between much greater ranges of temperature, as much as three-quarters of the whole heat supplied could be converted into mechanical effect. Thus, if an engine could be constructed which received the heated body, whether steam, air, ether, a gaseous, a liquid, or a solid, at a temperature of 1,200° or 1,300° Fahr. instead of at 284° as in the Fowey Consols Engine, and parted with the heated body at about 85° Fahr., then three-fourths of the whole heat supplied might be converted into mechanical effect.

It was a problem to be worked out, whether an engine could be constructed which should receive the working body at such a high temperature as that; nevertheless, there was this problem presented to Engineers, that whereas by attention to details they could only hope to save from 20 per cent. to 30 per cent. in fuel; by devising an engine to work between the temperatures mentioned, they could effect a further saving of 2 lbs. of coal out of every 3 lbs. now used. In the present state of knowledge this might appear

visionary; but if the remarks he had made should induce any member to undertake experiments, so conducted as to allow of an exact comparison between the registered H.P. of an engine, and the duty deduced from the dynamic theory of heat simply, he did not think the time of the Institution would have been unprofitably occupied.

Mr. Charles Greaves observed, that the inquiry proposed by the Author, although interesting, might be considered to belong chiefly to the county of Cornwall, where all the interests affecting the question of the decrease of duty, and the reason for such a decrease, might be found collected. Not being interested in mining operations, however, he would not have ventured to say anything, but for the fact, that the Cornish practices had been so largely introduced into waterworks machinery, and with such palpable success, that a strong relationship has been established with the mines themselves.

There could be no doubt, that the use of high-pressure steam and expansion, with its aids and adjuncts, had been a course of progressive discovery; that for a long time progress was made much more experimentally than theoretically. Indeed, the philosophical help rendered to the subject was very small throughout, and at the best, in the days of Davies Gilbert, Mr. Davey, Mr. Enys, or Messrs. Taylor, consisted more in explaining what had been accomplished, than in exhibiting any new path for improvement. Those men not only lent the subject great aid and support, but being perfectly disinterested, they supplied the verification that was wanted, both before, and up to 1840, or 1842, when the performance in duty reached its culminating point. Though throughout the progress of the question it appeared to have been forgotten, that there was an ultimate and impassable maximum; that the rate of boiler evaporation and expansion, and the comparative volumes, defined the utmost duty that could be obtained, even theoretically with the absence of friction, and with a perfect vacuum. Under the circumstances, competition was invaluable, and correct and fair reporting was the best incentive to competition. The impression rightly got abroad that the working of many mines and lodes might be indefinitely cheapened. Many paying mines existed in which higher profits were to be expected from a better removal of the water, and from a cheaper system; and the construction of downright shafts for the pumping engines was easily brought about in mines already lucrative, by which the performance of higher duty was further facilitated. This was material, because in sinking new mines, the pumping shaft was only an enlargement of the workings on the inclination of the lode, and was necessarily carried in a line entailing increased friction; the direction of the pull of the pit-rods being continually changed by

cranks and underlays, 'V bobs,' 'K bobs,' flat rods and guides—these again adding immense weight, which had to be counterbalanced by underground bobs and balance boxes. The 100-inch cylinder engine at Wheal Vor was said, when last at work, to have put 700 tons of pit-work in motion at every stroke. Of course such a condition would not admit of high duty.

Notwithstanding the honesty and sincerity evinced by the general acquiescence in a common reporter, there were grounds for supposing that the duty of the engines in Cornwall had been stated too high; as indeed was natural, because the general and continuous increase in duty for so long a series of years bred a popular local enthusiasm, and a disposition to extravagant statements, till at last, no one seemed to think that there was any real limit to the duty of those engines. On set trials, it was held to be perfectly fair to get the best coal (which was always measured in a bushel barrow), plenty of grease, to have all the gland bolts only hand-tight, to leave a hollow fire which would fall in as soon as the trial was over, and to let the lower lift of the pump run short of water, so long as the top one showed full. Besides, twenty-four hours' work was, at best, a test fallaciously short, and on long trials, if an engine was working fast to empty a mine, the duty would be low, and omitted from report or comparison, and cases were known where a deficiency of 400 tons or 500 tons of coal was discovered at stock-taking, which implied an excessive quotation of duty.

It might even be affirmed, that in many cases a lower expansion and a lower duty were more economical than a higher expansion and a higher duty, taking into account the dimensions of engines and the cost of pumps and pit-work. The majority of accidents which happened to mine-pumping apparatus arose from the giving way, or pulling asunder of pit rods, and higher expansion necessarily increased the suddenness and violence of the blow or jerk. In a water-works engine, a 10-feet stroke, cut off at $\frac{1}{4}$, was commonly made in 1 second; in a mine-pump with the same steam and expansion, $2\frac{1}{2}$ seconds were usually occupied, showing the length of time required to get all in motion, whereby also a greater uniformity in velocity was produced throughout the stroke. The engines which really did remarkably high duty in Cornwall were lightly loaded at the time; the load of the same engines might possibly have been much increased since then, but the management of the engine machinery was different from that of former times. Mines were now mostly managed by committees of adventurers, each probably trading with the mine in some department. Coals, timber, iron-work, stores, were thus supplied; and it was of little use under such circumstances for the Engineer to find fault with the coals he had to burn.

He quite agreed with the opinion expressed in the Paper, that a resumption of reporting would produce benefit, that the indicator

should not be neglected, and that the separate efficiency of the boilers should be ascertained. He knew for a fact that the use of the Cornish engine in South Wales, Lancashire, and other more northern parts of the country, had put many mines in better condition, without reaching those extravagant quotations of duty which were published twenty years ago, and which probably the augmented value of ore, the absence of reporting, the overloading of the engines, and the increasing scarcity of good condensing and feed water, would prevent them again attaining. The difficulty of finding a sensible, conscientious, and judicious Reporter must not be forgotten. Great praise was therefore due to Messrs. Lean for the many years of excellent reports so successfully carried on.

Mr. Morris remarked, that it had been said that the Cornish engines were better adapted for the Cornish work, than as pumping engines for waterworks. It would appear that was hardly the fact, for, while the duty of the engines in Cornwall had diminished, the duty of similar engines, pumping water in London, had gone on increasing. The result of fourteen years' experience in the working of Cornish engines under his charge, had been an uniform duty of 85 millions, using the best coals at 25*s.* per ton, though now, at the Kent Waterworks, he did not get a higher duty than 75 millions, because inferior coals were used at 10*s.* per ton. With reference to the objection, that the Cornish engine did not maintain an uniform pressure in the mains, he would say, at those works the pressure was uniform. This arose, not from any alteration of the engine, which was single acting, but from a modification of the pumps, which formed no part of the Cornish engine. All the pumps were double-acting, and could be worked without varying the pressure in the mains, with, or without a reservoir, and without a stand-pipe. At the Kent Waterworks, the Cornish engines used, were two, with cylinders of 70 inches and 10-feet stroke; two with cylinders of 60 inches, and two smaller ones. He had not had the slightest accident with these engines, and the expansion was not more than one-fifth. He was not prepared to go further into the subject at that moment, but would state, that in his opinion, the Cornish engine was well adapted for pumping water into towns.

Mr. Simpson, Past President, stated that the high-pressure, condensing, double-cylinder engines erected at Ditton, for the Lambeth Waterworks Company, and at Kingston, for the Chelsea Waterworks Company, could usually accomplish, in ordinary work, 90 million lbs., raised 1 foot high, per cwt. of coal, and could regulate the supply of water with the greatest ease. At Ditton, the engines supplied, in part, directly from the main, and were found exceedingly convenient. At Kingston, the lift was direct to an elevated reservoir 6 miles distant; the engines worked steadily, notwithstanding the variations in speed, according to the quantity of water

supplied. The engines frequently worked at the rate of 16 strokes per minute, and in the summer, when there was a pressing demand for water, had even, for a few hours consecutively, reached 18 strokes per minute. More complete details of the performance of the above engines would be found in the following extracts, from the Reports of the late Mr. Joshua Field and of Mr. E. A. Cowper (M. Inst. C. E.). Mr. Field stated, Jan. 7, 1853, with reference to the engines at Thames Ditton:—

"I have tested the performance of the engines made and erected for you by Messrs. Simpson and Company, by a trial of 24 hours' duration. The result was, that they delivered into the reservoirs at Brixton 9,960,226 gallons of water in that time, with a consumption of 23,400 lbs. of coal.

"During part of the trial they were pumping at the rate of 10,500,000 gallons per 24 hours, and they are quite capable of supplying this quantity of water, or more, in the same time, if required.

"The consumption of fuel being so much under that guaranteed by the contract, I did not consider it necessary to continue the trial longer.

"The pressure in the main having been carefully measured during the experiment, I find that the work done by the pumps is equal to 97,064,894 lbs., raised 1 foot high for every 112 lbs. of coal consumed; and this includes friction of the engines and pumps, and the power required for working the air-pumps, feed and charging pumps, and raising the water for condensation."

Of the two pairs of engines at Kingston, Mr. Field observed, that—

"The trial was continued for 24 hours, the coal consumed and the work done being accurately noted—the fires at the commencement and close of the experiment being fully charged with coal—the average number of revolutions of the engines was 14·44 per minute. The water was delivered from the pumps under a pressure, as indicated by a mercurial and a Bourdon's gauge, of 234¾ feet, being an average of observations taken every half hour.

"The quantity of water delivered into the reservoir was 11,287,208 gallons in 24 hours.

"The quantity of coal consumed in 24 hours was 255 cwt.

"The duty therefore of 112 lbs. of coal was 103·9 millions of pounds raised 1 foot high.

"After the experiment of 24 hours was ended, one pair of engines was stopped, and the other pair worked at such a rate as to raise 7½ millions of gallons in 24 hours. These were then stopped, and the other pair worked up to the same speed.

"The boilers, engines, and pumps performed in a most satisfactory manner."

Mr. Cowper's statement was as follows:—

"I have calculated out the whole of the extended experiments which I made of the regular working of the four engines at the Chelsea Water-works Company's pumping station at Kingston, and below is a general report of the result, and the details of the mode in which the particulars were taken during the working.

"The engines were, I believe, in their usual working order, and I was informed that neither pistons, nor valves had been taken out for some considerable time; and I therefore consider that the results obtained were

such as are commonly attained in regular practice, and cannot be considered as experimental, or exceptional results.

"I determined to have nearly a week's trial, continued day and night, and, had the duty varied to any considerable extent, I should have thought it right to have continued the examination longer; but I found that each 24 hours' results were so very nearly the same as those that had gone before, that I stopped at the end of the fourth day and night.

"I may state also, that we pumped so much water with all four engines going, that a vast quantity had to be run to waste at the reservoir.

"The final average result, at the end of the four days and nights, was a duty of 87,132,255 lbs. lifted 1 foot high by 112 lbs. of Welsh coal.

"The results of each 24 hours' work were calculated out separately, although the engines were not stopped (with one exception) but continued working right on. The results are as follows :—

	Lbs. 1 Foot per Cwt.	
"11th and 12th June, 1861,	86,758,778.	Two engines were at work.
12th and 13th „ „	86,829,785.	Four engines were at work.
13th and 14th „ „	87,866,594.	„ „ „
14th and 15th „ „	87,073,863.	„ „ „
Average . .	87,132,255	

"So that the difference between the highest and lowest duty was only a little over a million pounds 1 foot high, out of 87 millions.

"With regard to the detail of the observations, I may mention, that I had every place well swept out and clean, and had the keys of the coal-store and boiler-house in my possession the whole time, and had there at all times two of my assistants, whom I could thoroughly trust, and sometimes three, besides being present a great part of the time myself.

"I had my own indicators fixed at various times at the top and bottom of each of the steam cylinders, and frequently took indicator figures, taking care to arrange that the same bulk of steam was indicated by the pair of indicators at the same time, the one being on the top of the high-pressure cylinder, whilst the other was at the bottom of the low-pressure cylinder, or *vice versâ*.

"There were eighty-four indicator figures taken altogether; but as they are so very similar, I have not troubled you with more than one pair (Fig. 2), taken whilst four engines were at work. (See next page.)

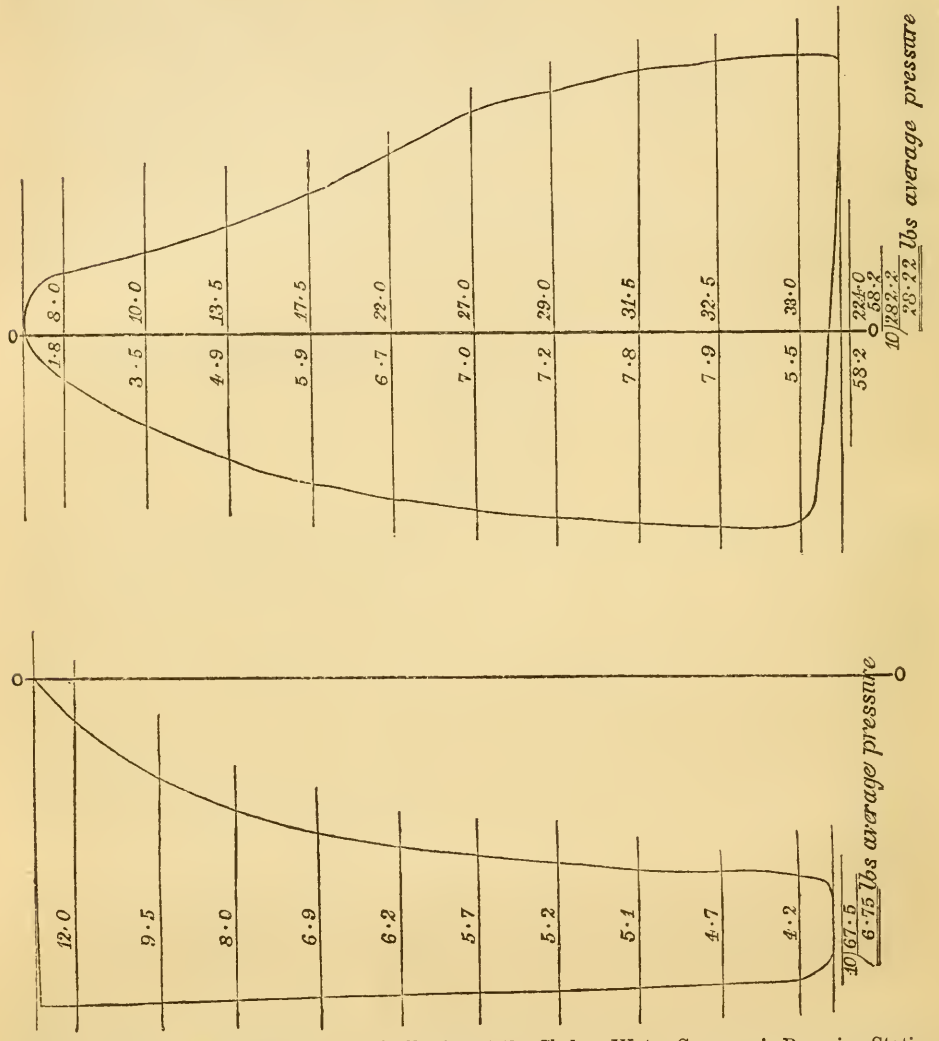
"I consider these indicator figures remarkably good, showing an expansion of the steam to about 9 times the bulk it has when cut off in the small cylinder. There is but very little difference in the pressure of the steam at the bottom of the piston of the high-pressure cylinder, and the top of the piston of the low-pressure cylinder. Generally it is only about half a pound, though just at the end of the stroke it is rather more.

"The H.P. of this particular pair of indicator figures amounts to 157, whilst the average work done in pumping the water amounts to 134·9. These results give a very close approximation; but I should call attention to the fact, that although the indicator figures have been compared carefully, and as good average figures as possible have been selected, yet it may by possibility have happened, that one engine of a pair had more, or less steam than its fellow, or that the engines were a little slow, or fast (and consequently working a little under or over their average power) at the moment the figures were taken, though I do not think that this was the case.

"The average vacuum maintained was 27·69 inches of mercury, though of course there were some variations, at different times of the day and night, with the different engines.

"The pressure of steam in the boilers was kept very steadily at 44·5 lbs. to 44·8 lbs.

Fig. 2.



Indicator figures from Messrs. Simpson's Engine at the Chelsea Water Company's Pumping Station, Kingston.

High-pressure cylinder, 28 inches diameter, 5 feet $6\frac{3}{8}$ inches stroke.
Low-pressure cylinder, 46 ,, ,, 8 ,, ,,

"The pressure of water in the pumping-main was taken by a mercury gauge, that I carefully proved myself. Observations were taken very frequently, and the average was taken out very exactly.

"The depth of water in the pumping-well was also taken carefully. The cold water pumped up from a depth for condensing purposes for the engine has been calculated as so much duty.

"The total number of strokes of each engine was taken by the counters, and the coal was weighed out in barrows containing 3 cwt. each, as it was taken from the coal-store, after which the coal-store was locked up.

"The engine and pumps work remarkably steadily and well, due, no doubt, partly to the fly-wheel crank and connecting-rod controlling the motion, and partly to the fact that the steam is properly cut off and

expanded in the small or high-pressure cylinder, before being allowed to pass on to the piston of the large, or low-pressure cylinder; thus preventing any excessive sudden pressure or blow on the pistons, or too great a variation in the total pressure throughout the stroke. The engines commonly run 14·7 revolutions per minute on a long average of working; and as the pump has a stroke of 6 feet 11 inches, this amounts to a bucket-speed of 203·4 feet per minute, or much faster than many engines that thump badly.

"There is no super-heating apparatus to these engines, and therefore there is still considerable margin, on which a saving of from 18 to 24 per cent. might readily be made."

Mr. F. J. Bramwell said, with reference to the opinion which had been expressed in favour of the Author's theory, that one cause of the falling off in these engines was excessive loading, even a cursory examination of Lean's 'Engine Reporter,' would show that was not the case. The 'Reporter' for February, 1862, stated the performance of thirty single-acting pumping engines; the nominal H.P. of these engines being calculated upon the assumption of the piston running 220 feet per minute (being 110 feet effective velocity), and on an average pressure of 12 lbs. per inch on the piston. The collective nominal H.P. thus calculated amounted to 9,518. Another column in the 'Reporter' showed the power developed, and that amounted only to 1,317 H.P., being in truth $\frac{2}{9}$ths only of the nominal H.P. He therefore thought it erroneous to suppose, that the falling off arose from the overloading. He had further tested this theory of the falling-off being due to overloading, by separate instances given in the 'Reporter,' when he found that the engine most loaded of all in relation to its nominal power, viz., loaded to the extent of 44 per cent., was doing the highest duty, viz., 72 millions. He found the next engine in the list was only loaded to 24 per cent., and that was doing only a duty of 39 millions. He found another loaded to 10 per cent. doing only 27 millions; so that it would appear that the engines which were least loaded were doing the least duty. He did not say that this followed throughout the whole list, but, as opposed to the overloading theory, it was a curious fact that the highest duty was done by the most heavily-loaded engines, and the lowest duty by one that was least loaded.

Another probable cause of the falling off was stated to be the pumping from diagonal shafts and rods, in lieu of perpendicular action. Yet in the 'Reporter' for February, 1862, it would be found, that though the engine doing the highest duty was drawing entirely perpendicularly, the next to it, which was also drawing perpendicularly, was only doing 39$\frac{1}{3}$ millions of duty; so that it did not appear that the low duty was owing entirely to the diagonal drawing. It could not be said, that he had compared very small engines with

very large ones, and that therefore the comparison was unfair (because there was a greater proportional leakage and condensation with a small engine than with a large one), as it would be seen in the 'Reporter' that a 50-inch cylinder loaded to 44 per cent. did a duty of 72 millions, while a 60-inch cylinder loaded to 24 per cent. was only doing 39 millions.

The next point to which he would direct attention was this, that the aggregate size of the cylinders of all the thirty engines amounted to an area that would be contained by a cylinder 28 feet in diameter, while all the work really done by them could be obtained, even from a single-acting engine (but worked at full power), by the employment of a cylinder of $13\frac{1}{4}$ feet in diameter. But the size which would do all the work, if the engine were double acting, would be as little as $9\frac{1}{3}$ feet diameter; therefore there was material and expenditure incurred by a cylinder of the enormous size of 28 feet, while the work done might have been performed by a cylinder $9\frac{1}{3}$ feet in diameter. There was, of course, the great money loss arising from the sunk capital, and he did not think this loss was compensated by the economy arising from light loading; for it appeared, it was not the lightest-loaded engines which gave the most economy. And even if there were an economy from light loading, it should be borne in mind that, taking the high price of 20*s*. per ton for coals, 1 lb. of coal per hour for twelve hours for six days in a week, would amount to only 36*s*. per annum.

Mr. G. H. Phipps said, that whilst so much importance was properly attributed to the use of high-pressure steam, accompanied with great expansion, in the rotary engines of the present day, the fact ought not to be lost sight of, that the Cornish engine had afforded numerous examples of the successful use of high-pressure steam and large expansion, perhaps half a century before the same advantages were secured for rotary engines. His old friend, Mr. Thomas Wicksteed (M. Inst. C.E.), had laboured most successfully to introduce that class of engine into the waterworks about London, in one of which, the East London Waterworks, more than double the quantity of water was pumped daily, when his improvements had been completed, over that supplied when he was first appointed Engineer, and this without any increase in the cost of pumping. On the question of proper and improper conditions, and where the Cornish engine might be employed, it seemed probable that where a large quantity of water had to be raised to a moderate height only, such for example as the sewage at Deptford, where the lift was only about 15 feet, the Cornish engine would work to a disadvantage. In such a case, the length of stroke of the pump would bear a large proportion to the total height of the column of fluid to be lifted, the consequence of which would be, he apprehended, a considerable acceleration to the water delivered during the first

half of the down stroke of the ram, and a corresponding loss of 'vis viva,' as well as loss from friction.

The above defect clearly did not apply when the length of stroke of the pump bore but a small proportion to the height of the column, such as in those waterworks where the engine worked against a column of perhaps more than 200 feet, and still less in the deep mines of Cornwall.

Mr. S. C. HOMERSHAM observed, that engines at Thames Ditton and at the Chelsea Waterworks were rotary, double-cylinder engines, with fly wheels, and, as had been stated, were doing a duty of 90 millions. He knew of other rotary engines of a similar description, but with single cylinders (made for the New River Company by Boulton and Watt), which were doing about the same duty. At Hampton Court there were six, or seven direct acting Cornish engines at work, pumping water from the Thames to the filter beds of the Grand Junction Waterworks, and to the filter beds of the Southwark Waterworks. The duty of those engines did not exceed 40 millions, or 50 millions. In other words, the rotary engines at Thames Ditton were doing 90 millions, whilst the others, only a short distance off, pumping the same description of water, under somewhat similar circumstances, were not doing more than 45 millions, or 50 millions. There could be no doubt, that for low lifts the Cornish engines, and especially the direct acting engines, were ill adapted; because among other reasons the pistons of the cylinders moved with such rapidity in the first instance, and the water had to be drawn so swiftly through the suction pipe and valve of the engine, that a large portion of the steam power was used in putting the water in motion through the suction pipe and suction valve to enable it to follow the plunger of the pump. Unless a Cornish engine had a heavy beam, or a beam heavily weighted on both sides, the steam could not be used with a high degree of expansion, inasmuch as the engine had not sufficient weight to be put in motion by the steam, so as to absorb the maximum power exerted by the steam. That was especially the case with the engines at Hampton Court, which were on the direct action, or what was known as the 'Bull' principle. The result of his experience was, that the expansive acting, rotary, fly wheel engine was the best that could be used for waterworks purposes, and especially for low lifts.

Mr. HUSBAND could not admit that the duty of the Cornish engines had fallen off, in the sense of the engines developing less power from a given amount of fuel. In the first place, diagonal shafts were more in use now than formerly. This was bad mining no doubt, as such shafts required diagonal rods to pass through them; and sometimes the shafts were turned to follow the dip of the ore. This, with the use of flat rods, was the most serious drawback to Cornish engines. Then, at the present day,

adventurers in many instances bought shares solely to deal with on the Stock Exchange, and paid no attention to the working of the mines, and to that lack of interest in the adventurers must be attributed the unscientific mining and all the evils resulting therefrom. It was certain, no class of proprietors could have had greater interest in employing engines which returned the best duty than Cornish men, because steam machinery absorbed a large proportion of the whole cost of the mine—in some cases to the extent of as much as 20 per cent. or 30 per cent.; therefore, since a mine was not a highly remunerative property, it was formerly of vital interest to the legitimate miner to obtain the best machinery, and every effort was made to do so.

It was interesting to trace the economical returns of the Cornish pumping engine from an early date. John Taylor gave the return, in 1769, at 5½ millions; in 1800, 20 millions; in 1815, 50 millions. In 1835 it was raised to 125 millions at Fowey Consols mine, where Austen's engine was used. It might almost be disputed whether such an amount of duty was ever done; but it was well authenticated by the report of the committee appointed. That work was done with a bushel of coals weighing 94 lbs.

Mr. Grout, formerly one of the Directors of the East London Waterworks Company, and Mr. John Taylor were the first persons who represented, in London, that such an amount of duty had been done in Cornwall. Mr. Wicksteed afterwards went into Cornwall, to experiment with these engines, and subsequently again introduced the subject in London, but it was still doubted by many whether the Cornish engines did the duty attributed to them, inasmuch as it was known, that the best engines of that time, made by Boulton and Watt, only did a duty, at the best, of 40 millions. There could be no doubt, however, that the principal advantage lay in the Cornish, or Trevithick's boiler and the use of high pressure steam. When the East London Waterworks Company first adopted the Cornish pumping engine, Harvey and Co. erected, at Bow, an 80-inch cylinder engine for them, which performed a duty of 90 millions. That engine had been in constant work from the year 1837 to the present time, without any accident whatever.

Prior to the introduction of the Cornish boiler into London, the old wagon boiler was used. The Cornish boiler allowed of working with higher steam, and a beginning was made with 30 lbs. pressure per square inch, working expansively, instead of 4 lbs. per square inch, with little or no expansion. The Cornish boiler was still retained, and was acknowledged to be the best, but the Cornish engine was thought, by many, to be inferior to the combined engine. In Cornwall the combined system was not now in use. It was, however, well understood, and had been extensively experi-

mented on there. Woolf introduced his combined rotary and pumping engines about the year 1812, the latter for the purpose of pumping single acting in mines; the first which were made in Wales and sent down to Cornwall, were the same in construction as the combined engines now used in London to pump water. A committee was appointed in 1814, by the Crenver Mine adventurers, to report upon the duty performed by Woolf's engine. The report made at that time was against the combined principle, but in the year 1824 Woolf constructed a combined engine with cylinders respectively of 70 inches and 40 inches in diameter, to pump water from the Great Alfred Mine. There was a single-acting engine with a cylinder of 90 inches in diameter, erected simultaneously on the same mine for pumping and for comparative experiment; the result, as to economy, was in favour of the single engine, and Woolf consequently abandoned the system of a combined engine for pumping water. About this time Gribble introduced his engine, similar in construction to the trunk engine. Attached to the piston, and projecting through the cylinder cover, was a second cylinder, or trunk, about half the sectional area of the large cylinder; the steam was admitted on the piston, filling the annular space round the trunk, and subsequently expanded below the piston, on the return stroke. This construction was also abandoned. Then followed Sims's engine, with one cylinder above the other; by this engine the practical difficulty of maintaining the combined cylinders in a parallel and vertical line was obviated. In 1844, an engine was constructed on this principle, with a cylinder of 100 inches below and a cylinder of 60 inches above, with a length of stroke of 10 feet, to drain the St. George Mine. The steam was admitted, first above the small piston, and expanded underneath the large piston. That plan was ultimately abandoned, the larger cylinder being removed, and the cylinder of 60 inches retained, for a single-acting engine to work in the usual manner.

The next kind of combined engine was erected and worked for three years under Mr. Husband's superintendence, for the drainage of the Haarlem Lake. There were three engines; in these the combined cylinders were placed one within the other, the internal cylinders being of 84 inches and the external cylinders of 144 inches in diameter, with a length of stroke of 10 feet. The steam was admitted at the top of the smaller piston, and expanded under both small and large; and he could speak from experience as to the way those engines worked. There was no difficulty in keeping the pistons tight and the vacuum good, and the result was better than that obtained from any other engine on the combined principle; the lake was successfully drained. But these, although excellent machines, were inferior in

economy to the single acting engine. Therefore it was not till every variety of experiment had been made in Cornwall, and elsewhere, that the conclusion was arrived at, that the single-acting engine was superior to all others yet tried. The combined principle was abandoned in Cornwall twenty-five years ago, with the exception of Sims's, and to the best of his knowledge, there was not a double cylinder engine now used for pumping in that county; and he could give no stronger argument than long experience supplied, that the double cylinder was unsuitable on the score of economy for pumping water in mines, or elsewhere.

One argument brought against the Cornish engines was, liability to accident, and that a high rate of expansion was synonymous with breakages, but he would adduce the authority of Mr. Grose, a Cornish Engineer of long experience, to show that accidents were never met with, except through the use of bad material. When high pressure steam was first used in Cornwall, accidents did indeed occur, because even new engines were not constructed strongly enough to stand the increased strain. Mr. Grose never worked more or less than three-fourths expansively, except for experiment, during a period of forty years. Some single acting engines at the Battersea Waterworks had been in incessant operation for twenty-two years, without a stoppage of twenty-four hours during the whole of that period, and he questioned whether any similar instance could be adduced, in the case of any other description of engine. Then again, at the Ipswich Waterworks, a rotary engine on Woolf's combined principle was erected about ten years ago, and a Cornish engine was erected in the same house about five years subsequently. Those engines were each of about 30 H.P. Both pumped from the same well into one reservoir; and the steam, for both, was supplied from the same boilers, and the Engineer, Mr. G. Hurwood, stated, that since the Cornish engine had been erected, the rotary engine was only used when packing the stuffing boxes of the Cornish engine, and that the economy in working the latter was as much as from 30 per cent. to 40 per cent. in its favour: also that he was satisfied with the soundness of the engine and its non-liability to accident.

Mr. Husband agreed with the Author in considering, that the calculation of work done as reported in Cornwall was fallacious, and approved highly of the proposition to report from indicator diagrams, for he had found a loss of 30 per cent., in some instances, by friction in comparing the indicated horse-power with the report calculated in the usual manner. He thought, if the system of reporting adopted in Cornwall had been adopted in London, where the friction of pump-work was trivial, Engineers would then have been in possession of interesting returns from the waterworks, and

those returns, if continued over the last ten years, would have been the best argument in favour of the Cornish system of pumping, and would have rendered much of this discussion unnecessary.

He then referred to a diagram taken from the cylinder of the Wheal Towan Engine, Cornwall—Mr. Grose, Engineer. The cylinder was 80 inches diameter, and the length of the stroke 10 feet; the pressure of the steam in the boiler was 62 lbs. per square inch; the initial pressure in the cylinder above the atmosphere was $12\frac{1}{4}$ lbs. per square inch; the final pressure being $7\frac{1}{2}$ lbs. below it. The ratio of expansion for valve was 1 in 4, the steam being much wire drawn. The duty was $81\frac{4}{10}$ millions when doing ordinary mining work. That engine had done a considerable duty with a heavy load. The pressure of the steam in the boilers was very high; but it would be seen, instead of running out the diagram square, the steam carried away the load and was wire drawn from the commencement of the stroke. There was, therefore, no horizontal line, as in the crank engine. There were exceptional cases to this, where the valves were very large; then the line on one diagram was square, up to the part of the stroke where the steam was cut off. That was a celebrated machine and a good sample of Cornish engine, and the diagram was taken under favourable circumstances.

Another diagram was taken from an engine at Wheal Tremayne mine. The cylinder was 60 inches in diameter, with a length of stroke of 10 feet; rods 40 fathoms perpendicular and 40 fathoms diagonal. The average pressure was 11·2 lbs. per square inch; the initial pressure 20 lbs.; the boiler pressure 40 lbs., expanded $\frac{2}{3}$rds of stroke; and the duty 40 millions. That was an unfavourable duty, but he gave it as taken from an engine doing average duty as reported in the Paper of the previous week.

The third diagram to which he would refer was from an engine with a cylinder of 70 inches diameter, erected at the Kent Waterworks in 1847. The length of the stroke was 10 feet; equal beam; the boiler pressure was 34 lbs. per square inch; the vacuum 27·6; the initial pressure 20 lbs. per square inch; the average pressure 13·64 lbs, expanding $\frac{3}{4}$ths of stroke; and the steam was wire drawn. That engine did a duty of 95 millions, working under peculiar circumstances.

It had been stated, that with the Cornish engine, it was impossible to pump through waterworks mains, that the pulsation and oscillation of the water were so great, that it was not adapted for that purpose, and that combined cylinder engines had been designed to obviate that difficulty. But at the time those engines were designed, that engine was in existence, and with double-acting pumps there was no difficulty in forcing water with regular flow through the mains, without more oscillation than was

due to a head of water of 3 feet or 4 feet. The double-acting pump got over the difficulty spoken of, and there was no standpipe. The diagram last alluded to showed that the Cornish engine did not require a heavy load attached to do good duty. The engine referred to was still working, and, he believed, it was in a thorough state of repair. He had been informed by Mr. Morris, the Engineer to the Kent Waterworks, that the average duty of that engine, as well as of a duplicate alongside it, was 75 millions, with screened coals at 10*s.* per ton. By using the Ebbw Vale steam coal, he believed there would be a difference of about 40 per cent. for steam purposes; for he had evaporated at the rate of 11 lbs. of water, with 1 lb. of Ebbw Vale coal, atmospheric pressure, and 4 lbs. per square foot of grate per hour. With London screened coal at 10*s.* per ton, there was 40 per cent. less value in steam, or about 8 lbs. of water were evaporated per lb. of coal, still, commercially considered, the screenings were most economical, the cost being one half of Welsh coal per ton. A good deal had been said about expanding steam to a great extent. He had long observed, that excessive expansion was not absolutely necessary to high duty. In the engines he had referred to for draining the Haarlem Lake, the steam in the small cylinder was cut off at about a quarter of the stroke, and ultimately expanded in the large cylinder 12 times. In Cornwall, at the Great Wheal Vor Mine, with a cylinder 100 inches in diameter, and a length of stroke of 11 feet, steam had been worked at half stroke frequently, and a duty of 80 millions had been obtained. In order to test that still farther, an experiment had been made at the Kew Waterworks with a cylinder of 90 inches diameter. The result had confirmed his opinion as to the high duty obtainable by wire-drawing steam and slow rate of expansion. The engine at Kew, with a cylinder of 90 inches, was worked eighteen hours with the steam cut off at about half the stroke. The steam was not finally cut off till five-eighths of the stroke were completed: consequently there was an expansion of three-fourths, with a pressure of 33 lbs. to the inch in the boiler. The duty was 97 millions—an extraordinary result; and he thought it would be found, and it was within his own experience in marine engines, that a high rate of expansion did not materially affect the duty of the engines.[1] The

[1] High duty with a low rate of expansion may be partly explained by the following reflection:—Suppose an engine develops a given power, as in the above case; first, with wire drawn steam cut off at half stroke, and secondly, steam full boiler pressure, cut off at one-sixth of the stroke. In the latter case, all the steam being admitted during the first sixth, will be exposed during the remaining five-sixths of the stroke to the cooling agency of the cylinder, piston, and cover. But in the first case all the steam for the full stroke will not have been admitted into the cylinder before the engine has completed fully half the stroke; thus exposing the whole volume of steam to the cooling effect of the cylinder, &c., only about one-third of

trial was made without any preparation of the engine; and he might state as a well-known fact, that practically expansion had not been carried out in Watt's engines in Cornwall, even by Watt himself. Watt's engines in that county had worked full steam for five-sixths of the stroke, and the remaining sixth only expanded, and with low pressure there was no advantage in working expansively. That was where Hornblower failed with his engine. He intended to work more expansively by the two cylinders; but his engine was a mere toy. It was never used with any success, neither could his plan of admitting steam only on the top of the pistons be successfully carried out, even with high pressure steam. The above engine at Kew had also been put on duty and worked with an expansion of five-sixths, that was, steam was admitted at one-sixth and expanded five-sixths. The record was taken during twenty-four hours with good north country coals, and a duty was reported of 114 millions. He was authorized by Mr. Quick of the Kew Works to state, that the engine did that duty in the ordinary course of working, and without any preparation; that the water was steadily lifted; and that the direct acting engines at Camden Hill, Kensington, did a duty of 75 millions with small screened coal. It had been said, that the Cornish engines were dangerous to handle; but there were at the present time thirty-five Cornish engines working in London on the single-acting principle; and those engines had been pumping 70 million gallons of water daily for seven years, absolutely without any accident; some of the water being pumped over twice. That was abundant proof that there was no extra danger in using the Cornish engine. He was aware, that double-acting, expansive, rotary engines were said to do high duty, and it had been stated, that unless the Cornish engine had a heavy weight attached to it, it would not perform a high duty. The diagram of the engine with a cylinder of 70 inches diameter proved, that the statement was unfounded, because that engine had only a load equal to half the pressure of the steam, which pumped water for half the stroke, and the remainder was pumped by the balance. It would, no doubt, be better if the balance could be altogether avoided. When the New River Company, not long since, erected their new engines, the question of the weighting or balance was discussed, as also the extent of the foundations required for the Cornish engines, and their advisers recommended fly-wheels, weighing nearly, he believed, 60 tons, intending thereby to cause the absorption of

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the time, as compared with the other case. This, when we consider the extreme sensitiveness of steam to loss of heat, and therefore pressure, by radiation, may in some measure reconcile practice with the theory. There is also a certain amount of expansion in wire drawing steam.—W. H.

the initial pressure of the steam to allow of high expansion, so that as the engine ran expansively, the wheels should yield up their latent power. He had been told, that the foundations were a source of great difficulty and had to be largely repaired in consequence of that mode of working, and that the high rate of expansion had to be abandoned.

With regard to Cornish boilers and Wagon boilers, if the wagon boiler was, as stated, superior for evaporating water why not adopt it? There was no difficulty in strengthening the latter to stand high pressure steam, and there was the advantage of its occupying much less space. Single-cylinder engines were no doubt superior, theoretically considered, and wherever a second cylinder was used, with the addition of fly-wheels (which were shown to be necessary for that kind of engine), a burthen was incurred which must lessen the duty of the engine.

The true secret of the high duty of the Cornish engine lay in the velocity of the piston indoors, which was often 600 feet per minute—a great velocity as compared with the piston of ordinary steam engines. Going out, when the water was pumped through the mains, the velocity was about 100 feet per minute, and consequently there was a minimum friction to discharge the water.

After due consideration of all the kinds of engines erected for waterworks, he believed it would be necessary to follow in the steps of the marine engineers, and to introduce direct-acting engines. At Camden Hill and other places, where such engines had been working under fair circumstances there had been good results. On that principle, an engine of 500 H.P. might be erected in a house twenty feet square without trouble. It was a most economical engine as to cost and space, and, being self-contained, required very little foundation; columns to carry the cylinders were all that was necessary. It worked well, was the best engine for such purposes, and would eventually be generally adopted.

Mr. Homersham remarked, that the elaborate experiments of Mr. Wicksteed showed that, per lb. of coal, precisely the same amount of water was evaporated by the Cornish boiler and the wagon boiler.

Mr. Thomas Webster said, that twenty-five years ago, as would be seen by reference to the Minutes of that date,[1] this question was discussed nearly in the same terms as it was on this occasion. A committee of the British Association was appointed in the year 1837, for the express purpose of investigating the question of the duty of the Cornish engine, and that committee, of which Mr. Enys was a leading member, reported in favour of the accuracy of the general results of the duty done, as recorded by

[1] *Vide* Minutes of Proceedings, Inst. C.E., vol. i. (1838), p. 2 (1840)., p. 1.

the Cornish Engineers, and against the conclusion of those who declared, that such an amount of duty as was claimed for those engines was impossible. It was mainly through Mr. Wicksteed's advocacy, that the Cornish boiler, and the Cornish system of pumping, were introduced into London. It would be an interesting matter of inquiry as to how far the discussion which took place in the Institution, in the year 1838, might have contributed to the result which had now been produced. It had been explained, that in Cornwall coal was very costly, that it was necessary to economize it as much as possible, and that the stroke was frequently cut off at $\frac{1}{4}$th; but, to the best of his recollection, he had seen in Cornwall engines cutting off at $\frac{1}{9}$th. The use of steam expansively was then in its infancy, and the whole matter seemed to have slept for a while; for if anything of importance had been done in the interval, it would, probably, have been brought before the Institution. He would add, that Mr. Josiah Parkes had explained the results of the Cornish engine, by considering the effects of what he called the percussive, or instantaneous action of high-pressure, steam, let in above the piston, in starting an enormous weight which, it was to be borne in mind, was a feature in the Cornish pumping-engine. Then, by cutting off at $\frac{1}{9}$th, the velocity was gradually reduced by the diminution of the pressure up to the end of the descent of the piston, when the momentum in one direction was exhausted, and the weight so raised through a fixed or definite distance, on the return stroke, raised the water at a slow velocity; then the steam was applied in a most efficient and economical manner, for that particular purpose of raising a great weight, which on its descent should pump the water. The material question for consideration appeared to be, whether the same capacity of work was attainable in the double-acting, or rotary steam-engine.

Mr. BEARDMORE said he was in the district when public attention was directed to the construction of the Fowey Consols engine, erected by Mr. West, a practical Cornish Mining Engineer, with the avowed intention of making an engine superior to every other of that date. Every care was taken to secure a maximum performance, the engine-men being anxious to get up the duty, as a matter of pride and competition; a duty of 125 millions was accomplished, and the engine was considered to be a marvel of perfection. But the duty was doubted at the time, and, in consequence, the engine was thoroughly tested before a committee of mining captains. The result was, that during the period of a month, the duty above stated was performed by the Fowey Consols engine. That was about the year 1835. The British Association, hearing of the trials, also appointed a committee to investigate the matter, and the results were fully confirmed. With

regard to the general question, no one could dispute for a moment that the Cornishmen were the first to apply the high steam combined with condensation, being compelled to use the utmost economy in fuel, from its high price. Taught by experience, they inclosed the cylinder-pipes and boilers in a covering of non-conducting material long before it was thought necessary to do so elsewhere; so that even before 1835 the temperature in an engine-house in Cornwall was not, generally, above 70°. But he thought, as was the case with every other kind of machinery, each description of engine had its appropriate employment. Nothing could compete with the Cornish engine for mine-pumping. The cylinder being placed within the engine-house, with the centre of the beam on the wall, and its outer end overhanging the pumping-shaft, there was no loss of power, as the weight of the pump-rods acted directly against the power at the opposite end of the beam; and thus, at every stroke, the greatest possible amount of effect was obtained from the steam, while the friction was reduced to a minimum. He conceived it impossible for a mining captain to think of putting a rotary engine, or even a double-cylinder engine, in such a position. With regard to the comparative merits of the wagon-shaped boiler and the Cornish boiler, he believed, that in the latter, the flues were better distributed and adapted to give a slower combustion with the small hard Welsh coal used in the mining districts; the boiler, being of smaller dimensions in its parts and circular in its form, was better able to resist the pressure of steam at 30 lbs. and upwards, then considered a high pressure, and for which the old wagon-boiler form of construction was not well adapted, as modern practice had fully shown. The great points in the Cornish engine and boiler were simplicity of construction, magnitude of power at each stroke, a large space for the expansion of steam, and the least quantity of waste. The various modifications of the Woolf, or double-cylinder engine, were equally applicable to the rotary class of work; and it was only necessary to point to the successful engines by Messrs. Simpson and Co., Messrs. James Watt and Co., and others, to show, that the same principle would produce as economical results. But, that the two engines were equally fitted to the same work, taking into consideration first cost and the applicability to its special position, he entirely denied. The modern pumping-engine, with double cylinders and a large fly-wheel, such as was now made, was as perfect a machine as could be imagined; but he also thought, that for mining purposes, the Cornish engine, as possessing a greater simplicity of parts, a more capacious cylinder, doing more duty with fewer strokes, and on account of its special adaptability to slow motion, for which it was invariably used, was equally perfect.

Mr. J. M. Heppel wished to bear testimony to the high

authority of Mr. West on this subject. About thirty years ago, on the occasion of Mr. Heppel's visit to Cornwall, Mr. West, who was known to him as having devoted considerable attention to the Cornish engines, took great pains to explain their working. Anything which Mr. West stated on these matters was deserving of attention, from his thorough practical knowledge of the subject, and from his having no further interest in the engines than a professional anxiety as to their working.

Mr. POLE stated that, having taken much interest both in the Cornish engine and in the other form of engine now being compared with it, he would offer a few remarks.

First, as to the Cornish engine. The principal object of the Paper, and of much of the discussion, related to the duty now obtained in Cornwall. That might safely be left in the hands of the Engineers of the locality. The Cornish Engineers deserved the greatest credit. After Watt's retirement from the county, in 1800, had left the engines in their hands, they had, by their continued efforts at improvement, raised the duty from 25 millions to 100 millions; and when it was asserted in other parts of the country, that this high duty had been performed, the statement was received with the utmost incredulity, until investigation verified the fact. Subsequently, engines made to a certain extent on the Cornish principle were used in London and elsewhere, and the results showed, that the duty obtained, although not so high as in Cornwall, was still much in advance of what had generally been obtained with ordinary engines.

It was important to determine how far the high performances of the Cornish engine warranted Engineers in using that form in other localities; and this was the point to which he would chiefly direct attention. Taking the high amount of duty as proved, it was necessary to inquire to what causes it was attributable, and then to see how far that peculiar form of engine was necessary in order to realize that amount. The causes had been well investigated, the conditions of working were well known, and followed the ordinary rules of mechanics, there was no great difficulty in tracing what features were, or were not, conducive to the increased duty.

Much economy had sometimes been thought to result from the arrangements of the Cornish boilers, and, in particular, from the slow combustion generally used. No doubt the Trevithick or Cornish boiler was an excellent form for high-pressure steam,[1] and it was quite true, that ample boiler provision was highly conducive to economy; but it had been proved, that the results produced by

[1] *Vide* "Pole on the Cornish Pumping Engine." London: Weale. Arts. 128 to 138.

rapid combustion might be as good as those produced by slow: and in any case it was manifest, that whatever was found to be beneficial in the Cornish boiler arrangements might be applied equally well to any other form of engine.

The greater perfection of vacuum was another cause of economy insisted on in the Cornish engines, as was also the great care taken to economize heat in every possible way: such as by careful clothing, by preventing steam from blowing away, by keeping the engine and boiler houses closed, and by many other minor precautions of the same kind. No doubt, considerable saving was thus effected; but it must at the same time be admitted, that these precautions were not peculiar to the Cornish engine, but would be equally applicable and equally advantageous in other forms of engine.

Passing over, therefore, all these subsidiary circumstances, he came to, what was allowed on all hands to be, the most important cause of the high duty of the Cornish engine, namely, the use of high pressure steam, expanded to a considerable extent after it was cut off from the boiler. The principle of expansion had been introduced by Watt, but without any remarkably beneficial effect. It was not till that principle was applied with high pressure steam by Woolf and Trevithick that it realised the great economical results of which it was capable.

Now, it was not to be denied that the single-acting pumping engine, as used in the Cornish mines, offered great facilities for the application of a high degree of expansion, chiefly on account of the great mass of matter put in motion. It was well known, that in deep mines the pump rods attached to the outer end of the beam, and extending down the deep shafts, were so heavy as to require what were termed 'balance bobs' to counterpoise the excess of weight beyond that required to work the pump plungers; and hence, the mass of matter to be moved at each stroke was exceedingly great. This, strange as it might at first sight appear, had a beneficial effect on the working of the engine; and indeed the increase of this mass, as the mines were worked deeper, was one of the principal causes of the rise of duty of the engines. The explanation of this fact was not so generally known as the fact itself; it lay in the circumstance that the great mass in motion moderated the velocity, and so allowed a higher pressure to be used at the commencement of the stroke, and a greater degree of expansion afterwards, from which, of course, a higher economy arose. If the high initial pressure were used with a small mass of matter, the velocity communicated to the piston would be so great, that the pump pistons would outrun the water, and the motion become unmanageable.

It was very common to hear objections expressed against the adoption, for non-mining purposes, of the great weight attached to

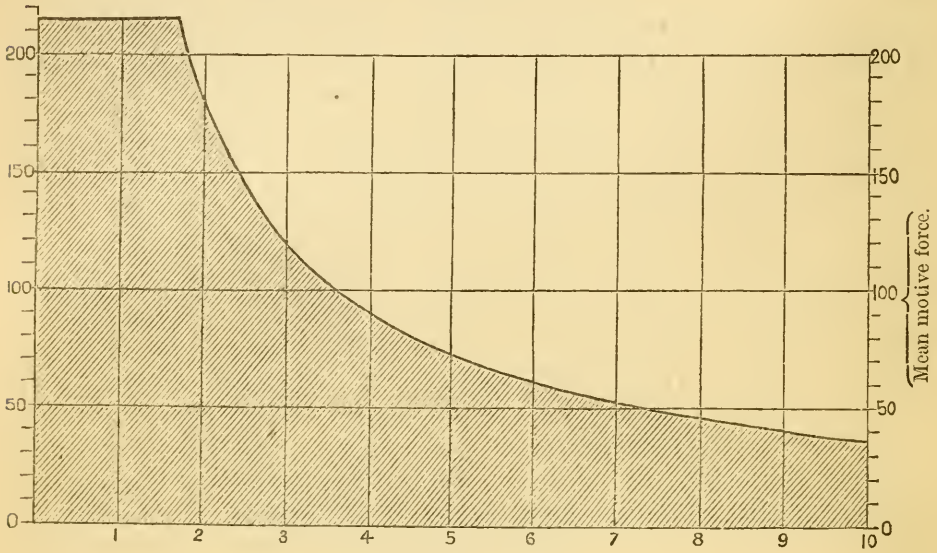
the engine, which was thought to be only a burdensome appendage, necessitated by the deep shafts, and forming no part of the economy of the engine itself. It had been imagined, that the principle of expansion could be applied just as well without the intervention of so many tons of matter; and attempts had actually been made to construct (so called) Cornish expansive engines on such a plan as to dispense with the surplus weight altogether. Of course, as could be easily foreseen, such attempts had been, and must be, failures. Not that it was absolutely necessary for a beam to intervene, for single-acting engines on the direct action principle were working successfully; but it was absolutely necessary that a certain mass of matter, in some shape or other, should be put in motion, to moderate the velocity inevitably produced by the initial excess of steam pressure, when expansion to any considerable extent was used. In proportion, then, as the velocity could be moderated by an increased mass of matter, so steam of higher pressure might be admitted, and a greater economy derived from expansion; and investigation demonstrated the rationale of the fact. Whenever, therefore, the Cornish engine was used in its single acting form, for pumping purposes, sufficient mass must be provided to control the motion, or else the expansion must be diminished, and the economy also.

But it was worth while inquiring, how the Cornish principle of high pressure steam, used with a considerable expansion, was capable of being applied in double acting engines for rotary motion, which were so much more common and in so much more general use than pumping engines. The difference was, that in the rotating engine the motion was controlled by a crank and fly-wheel, and the piston could not give way so freely under the impulse of the initial steam pressure as in the pumping engine; and as a consequence, the great initial pressure at the commencement of the stroke produced violent strains on the machinery, which were exceedingly prejudicial to the working and to the durability of the engine.

To illustrate this, it was desirable to consider the great irregularity of pressure upon the piston at different parts of the stroke. For example, if the steam were expanded in a single-cylinder engine to six times its volume (by cutting it off after $\frac{1}{6}$th of the stroke was passed over), the moving force acting on the piston would be six times as great at the commencement of the stroke as at the end. The diagram, Fig. 3, was intended to represent the steam's varying pressure throughout the stroke. It showed that, assuming the mean motive pressure to be = 100, the pressure at the commencement would be = 214, and at the end only 36, giving an irregularity of 178. It was evident, that the effect of the great excess of pressure would be, to give a heavy blow to the

piston at the beginning of every stroke, which must produce violent concussions through the whole of the machinery, and tend to cause much danger and inconvenience in the working. In proportion

Fig. 3.



Single Cylinder Engine.
Steam cut off at one-sixth stroke. Initial stroke 2·14 times mean motive force.

as a greater degree of expansion was used, the evil would be proportionately greater. Thus, if 10 times expansion were used, the blow at the commencement would be = 302, while the mean motive force or power of the engine was still only = 100 as before.

For this reason it had been found difficult to carry the degree of expansion and the consequent economy to the same extent with the rotary, as with the Cornish single acting pumping engine, in which the piston and all its appendages were free to move in proportion to the steam pressure, and therefore the excess at the commencement was at once absorbed in giving velocity to the heavy mass. In a rotating engine, on the contrary, the motion of the piston being controlled by the crank and fly-wheel, the piston resisted the violent impact which occurred just at the point where it was least able to give way; and the consequence was a violent strain, which was repeated many times every minute, and which must ultimately have a prejudicial effect on the machinery.

With respect to the other form of engine which had been alluded to, namely, with the compound or double-cylinder, the principal reason why this engine deserved mention on the present occasion, was, that it furnished a means of applying the principle of expansion to a large and beneficial extent, without encountering the accompanying evils, before mentioned as inherent in the Cornish or

single-cylinder form. It was not only capable of doing as high a duty as the Cornish engine, but had special advantages peculiar to itself, particularly as regarded equality of action, and freedom from the injurious concussions and strains to which single-cylinder engines acting with high expansion were exposed.

The double-cylinder engine was invented by Jonathan Hornblower, a mechanical Engineer of considerable eminence in Cornwall, who took an important part in the application of the steam engine in that district during the early part of Watt's career. The idea appeared to have occurred to him early in the year 1776, if not before. He experimented upon a large working model, the cylinders of which were of 11 inches and 14 inches diameter respectively; and he patented his invention on the 13th of July, 1781. The patent contains several inventions relative to the steam engine, all shortly, but clearly described; the first and second ran as follows:—

"First. I use two vessels in which the steam is to act, and which in other steam engines are generally called cylinders.

"Secondly. I employ the steam after it has acted on the first vessel to operate a second time on the other, by permitting it to expand itself, which I do by connecting the vessels together, and forming proper channels and apertures, whereby the steam shall occasionally go in and out of the said vessels."

The third invention was for surface condensing, very much applied in modern days: the fourth, fifth, and sixth referred to means of getting rid of the air and condensed water: the seventh was a steam piston, which, varied into a steam stuffing-box, was in common use at the present time.

Here, therefore, was found, clearly developed, the theoretical principle, as well as the practical application of the expansion of steam; and it was beyond dispute, that that patent of Hornblower's was the first publication of the principle to the world. Its discovery, however, was usually ascribed to Watt, on the strength of a letter written by him to his friend Dr. Small, of Birmingham, as early as 1769, twelve years before Hornblower's patent, in which he gave a clear and explicit description of the general principle. Notwithstanding, however, the large practice Watt had about this time, it did not appear that he ever applied expansion with any view to economy in its use, till 1776, when an engine at the Soho Works was altered to work expansively. In 1778 another engine, at Shadwell, was experimented upon, and Watt took out his expansion patent on the 12th of March, 1782, eight months after the date of that of Hornblower.

The over-zealous friends of Watt, in a spirit so contrary to that of the great man himself, thought it necessary to exalt his fame by damaging that of everybody else, and had charged Horn-

blower with pirating the principle, from surreptitious information of Watt's experiments, but no proof was ever given of the accusation. It was highly improbable, and altogether negatived by the fact, that the originality of the invention, on Hornblower's part, was expressly admitted by Watt himself. In regard, then, to the expansive use of steam (one of the most important and valuable principles in the whole range of practical science) it was clear that the discovery was original, both with Watt and Hornblower; and that although Watt established the priority of idea, the first publication to the world was made by Hornblower in the double-cylinder engine.

Hornblower, after some years' delay, proceeded to manufacture his engines in Cornwall, and as soon as the miners perceived that the invention acted tolerably well, they took advantage of it somewhat largely, and in some cases endeavoured to make it supersede Watt's single-cylinder expansive engine, which had also then been brought largely into use. But, as it was impossible to make Hornblower's engine work well, without using Watt's separate condenser, claimed in his patent of 1769, the competition could not be kept up; damages were obtained against all who had infringed Watt's patent, and the double-cylinder engine fell, for a time, into disuse.

Both Watt and Hornblower had failed to perceive, that to work the principle of expansion to its full value, it was necessary that the steam should be admitted, in the first instance, at considerable pressure. Down to the year 1814, the pressure of the steam in the Cornish engines never much exceeded that of the atmosphere, and so little economy resulted in practice from the application of expansion in that way, that it was found scarcely worth using at all; and, indeed, after Watt's immediate connection with the county ceased, it was rapidly becoming disused and forgotten. The merit of rescuing it from that desuetude, belonged to two Cornish men, Richard Trevithick and Arthur Woolf, who both, about the same time, introduced into their native district the true secret of beneficial expansion, namely, the use of high pressure steam. Trevithick applied the system to Watt's form of engine, the single-cylinder; Woolf applied it to Hornblower's, the double-cylinder engine. The two forms of machine thus for the second time became rivals; and competed well with each other for many years; but Mr. Pole would confine his remarks to Woolf's modification only. Woolf took out his patent, while residing in London, in June, 1804. His invention consisted simply in the application of high-pressure steam to Hornblower's engine, which he also made double acting, to fit it for rotary motion, after the example set by Watt long before. It was obvious, therefore, that the name "Woolf's Engine," by which that machine was

so often designated, was quite erroneous. The machine was wholly and solely Hornblower's invention, and had no more right to be called Woolf's, than had the present Cornish engine to be called Trevithick's; for Trevithick made the same change with the latter engine as Woolf did with the former. Yet no one would think of disconnecting Watt's name with his engine on that account: and on the same principle Hornblower ought not to be deprived of the credit which the association of the name with his own invention should secure to his memory.

Woolf's first engine was erected at Meux's brewery in London (to which establishment he was Engineer) in 1806, and subsequently others were fixed in various manufactories; but those engines did little more than serve him as experiments, until 1813, when he returned to reside in Cornwall. There he found a wide field open for his improvements. He entered earnestly into the manufacture of his engines, and with great success. He at once raised the duty from about 20 millions, at which Watt had left it, to between 50 millions and 60 millions, so saving two-thirds of the fuel employed.

But though Woolf was so successful, the Cornish Engineers soon began to see that Trevithick's plan of using high-pressure steam expansively, in a single cylinder, promised equally good results with Woolf's, and, at the same time, was free from the greater complexity of the double-cylinder arrangement. Trials on a large scale, in which even Woolf himself was persuaded to assist, soon demonstrated this to be true; the more expensive contrivance began to be disused in the mines, and the Cornish engine gradually settled down into its simplest form, viz., a single engine on Boulton and Watt's construction, but with Trevithick's high-pressure steam, and high-pressure boiler, which was the form it had retained to the present day.

It was thus seen, that although the compound-cylinder engine was the first mode in which the principle of expansion was introduced to the world, and, about 30 years afterwards, was also the first mode in which this principle was made effective and advantageous, yet, that in both cases, it was ultimately superseded by the more simple form.

It remained now to give some account of the third era of prominence obtained by this form of engine; namely, its revival in the present day. That revival had been promoted by many modern Engineers; but Mr. Pole considered it to be the safest course to confine himself simply to the statement of his own experience.

In the year 1848, the Lambeth Waterworks Company, on the advice of their Engineer, Mr. James Simpson, took the bold measure of proposing to remove their source of supply to the banks

of the Thames, above the tide-way at Long Ditton; and as a part of that scheme, it became necessary to force the water, by steam-pumping power, along a cast-iron main, 10 miles long and 30 inches in diameter, from the source at Ditton to the Company's reservoirs at Brixton Hill. That problem was a difficult one, no experience on so great a length of large main having been then obtained. The great mass of water in motion along the main, combined with the fragile nature of the material, rendered it essential that the motion should go on in the most equable manner, and that all concussions or irregularities in the pressure should be, as much as possible, avoided, or frequent fracture of the pipes, fraught with the most serious consequences, might be looked upon as almost certain. At the same time, from the large steam power required, it became necessary that the Company should avail themselves of all possible improvements in regard to the economy of fuel. At that time, the Cornish single-cylinder expansive engine, which had been introduced into London by Mr. Wicksteed, had been somewhat extensively tried for waterworks purposes, and had justified the well-known reputation of Cornish engines for economy; but, as great objections appeared to present themselves in this case, on account of the irregularity of the single action, Mr. Simpson determined to have the whole subject investigated, with a view to ascertain whether the other form of expansion engine, the compound cylinder, would not prove more applicable.[1]

It was found, that the double-cylinder engine had already been, to some extent, revived, and that modern examples of it, some of considerable size, were working in various parts of the country. These were visited, and their action was carefully examined, but it did not satisfactorily appear that any then met with were sufficiently favourable instances of the application of the principle. The expansion had not been carried to a sufficient extent to produce great economy, nor had it been arranged in the best manner to attain equality of motion; and the arrangements of the valves and passages were generally so defective as to cause great loss of power and waste of fuel.

Notwithstanding those unfavourable results, an attentive study of the principles of the engine led to the conclusion, that with a well-considered design, carefully carried out into practice, the compound-cylinder arrangement promised not only to be eminently suited to the case in question, but also generally to offer a more beneficial application of the principle of expansion to engines for rotary motion, than could be attained by the single-cylinder form.

In accordance with these views, when the Lambeth Water-

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[1] This investigation was intrusted to Mr. Pole, in conjunction with Mr. David Thomson.

works extension scheme was carried into effect, large engines of 600 H.P. were carefully designed, and as carefully constructed. The result fully justified the expectations entertained; the use of similar engines was speedily and largely extended to other cases; and the soundness of this principle of construction might be now said to have been fully proved.

In comparing the double- with the single-cylinder engine, it would be a mistake to suppose, that there was any theoretical advantage, either on one side or the other, in regard to the economical effect of the expansion. It had been shown by Watt, in an ingenious way, at a very early period, and could be demonstrated theoretically, that if the steam were expanded to the same extent, the economical advantage derivable from the expansion would be precisely the same, whichever form of engine was adopted.[1] And it further resulted from the principles of the engine, that, for a given initial pressure of steam and degree of expansion, the power of the engine, measured by the work done at each stroke, depended on the size of the large cylinder only, and was precisely the same as that produced in a single expansion cylinder of the same capacity. The small cylinder had no effect in adding power, but was merely an appendage, useful only for modifying the arrangement of the expansion, and equalizing the steam's action during the stroke.

He would now endeavour to explain in what way the compound cylinder engine might be made to effect the important object, of obtaining the economical benefit of a large degree of expansion, without the inconvenience of the great inequality of pressure in the single cylinder.

In the original compound cylinder engines, as patented by Hornblower and Woolf, the steam was allowed to act first in the small cylinder, at full pressure throughout the whole of its length, and then to expand into the larger one; the proportionate cubic content of the two cylinders thus defining the degree of expansion made use of; and it was believed, that this method of working had been that most commonly used down to the time of the investigations before referred to. But an inquiry into the principles of action of the engine showed, that it was most advisable not to allow the steam to enter the small cylinder during the whole stroke, but to cut it off after a certain portion of the stroke had been passed over, and to allow the expansion to commence at that point; and it was an important fact, which Mr. Pole believed not to have been known, until published by himself and Mr. Thomson in 1851, that there was a certain part of the stroke (depending on the degree of expansion made use of) at which it was more advan-

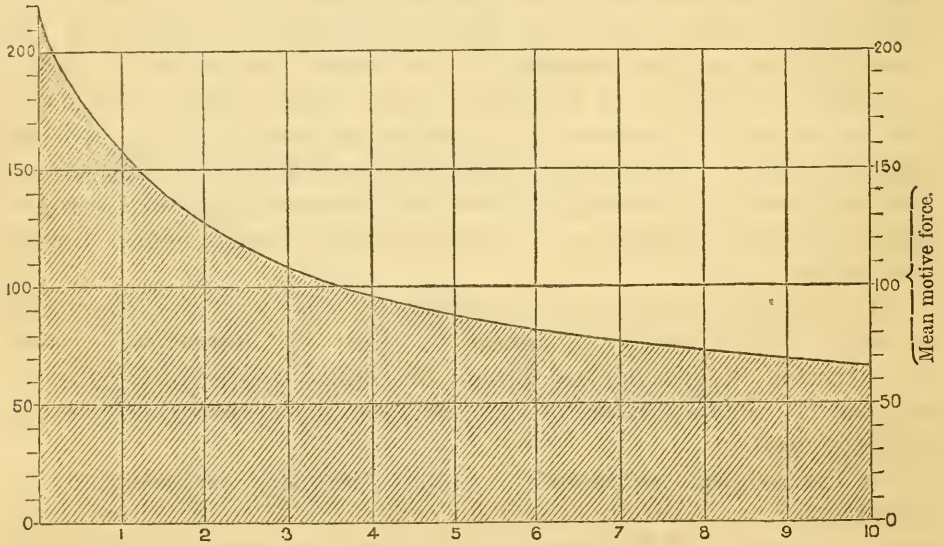
[1] *Vide* note, p. 97.

tageous to cut off the steam than at any other, by reason that the irregularity in the moving force, which it was so desirable to mitigate, was then reduced to a minimum.

For example, if the mean moving force or power of the engine was = 100, and the extent of expansion adopted was six times, then the initial force, or blow on the piston, at the commencement of the stroke would be, in a single-cylinder engine = 214; in a double-cylinder engine, if the steam were allowed to enter during the whole of the stroke of the small cylinder = 214; if cut off at $\frac{41}{100}$ths of the stroke = 140; if cut off at $\frac{1}{4}$ of the stroke it would be = 161.

The diagrams Figs. 4 and 5, showed a comparison of these cases throughout the whole stroke of both kinds of engines.

Fig. 4.

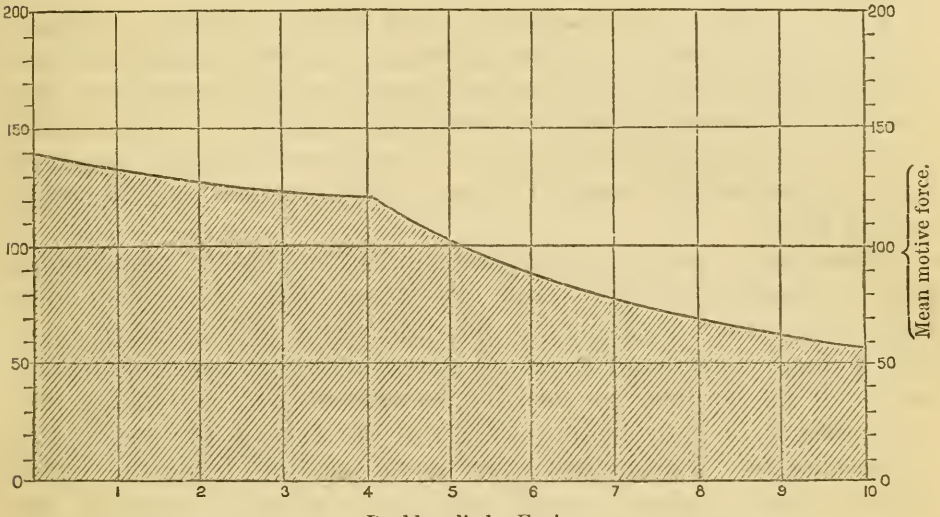


Double-cylinder Engine.
Steam cut off at end of stroke in small cylinder. Initial blow 2·14 times mean motive force.

It would thus be seen, that, as regarded a degree of expansion of six times:—(*a.*) If this expansion was effected in a single cylinder the machinery of the engine would have to bear a sudden blow, at the commencement of the stroke, no less than 114 per cent. greater than the mean force due to the effective power of the engine. (*b.*) If a double-cylinder engine was employed, and the steam allowed to enter during the whole stroke of the small cylinder, but little improvement was effected; the blow at the commencement being as great as in the single cylinder, only lasting a shorter time. (*c.*) But if the same engine was so arranged that the steam was shut off in the small cylinder at a certain point of the stroke, the excess of pressure or initial blow, might be reduced from 114 per cent. to 40 per cent. above the mean; and thus a real and most beneficial improvement would be effected in its action.

This advantageous point of the stroke might be easily determined by calculation, and it varied with the extent of expansion.

Fig. 5.



Double-cylinder Engine.
Steam cut off at $\frac{41}{100}$ths stroke in small cylinder. Initial blow 1·40 times mean motive force.

The following Table would show the results for various degrees. The first column contained the given extent of expansion; the second gave the size of the small cylinder in proportion to the large one; the third, the proportion of the stroke at which the steam should be cut off; the fourth, fifth, and sixth, showed the comparative advantage of the double over the single cylinder.

Extent of Expansion.	Cubic Contents of Small Cylinder, that of Large Cylinder being 1. (Equation XIV.)	Fraction of Stroke in Small Cylinder, where Steam should be cut off.	Mean Motive Force. (Equation XIII.)	Initial Blow.	
				Single Cylinder. (Equation XII.)	Double Cylinder. (Equation XI.)
4 times	0·50	0·50	100	168	126
6 times	0·41	0·41	100	214	140
8 times	0·35	0·35	100	260	151
10 times	0·32	0·32	100	302	161

So that, for a high degree of expansion, the excess of the initial blow over the mean force was less than one-third as great in the double cylinder as in the single one. It was clear, that the value of this initial blow expressed the maximum strain on the whole of the machinery, by which the steam power was transmitted from the piston to the fly-wheel; and consequently, determined the strength of the various parts necessary to resist that strain.

Hence, in proportion as this initial blow could be reduced, all those moving parts were required to be less massive in construction, and were subject to much less violent causes of fracture and derangement.

Another point to which attention was directed, was the arrangement of the valves and steam passages. It was found that the valves commonly used were not only complicated, inconvenient, and expensive in construction, but were also wasteful in action; the great size and disadvantageous arrangements of the passages causing considerable waste of steam, and consequent loss of power and of fuel.

There was a peculiarity in that kind of engine, in requiring a pipe or passage, through which the steam must travel from one end of the small cylinder to the other end of the large one; and a little consideration would show, that that pipe should be as small in content as possible, consistent with admitting the free passage of the steam. When at the end of the stroke, the communication was opened, the steam passing from the small cylinder must expand, to fill that pipe, before it entered the large one; and if the passage were large, the steam necessarily suffered a reduction of pressure in so doing, which seriously diminished its effective action on the large piston during the future stroke, and so caused much loss. In some engines, the loss was so great as to waste nearly half the power of the engine, and, even in the best, almost to neutralize the benefit of expansion. It was, therefore, found essential to the success of the engine, that some arrangement should be adopted which should satisfy the following conditions:—1st. That the valves should be of the simplest possible character and free from liability to derangement. 2nd. That the valves should admit of the steam being cut off from the small cylinder at such a point as might be necessary to secure the equalizing results before described; and—3rd. That the clearance spaces should have the smallest content possible; and in particular, that the pipe between the two cylinders should be direct and unimpeded, and of no larger capacity than was absolutely necessary for the passage of the steam; and, as further conducive to economy, that this pipe, if possible, should never be opened either to the high-pressure steam, or to the condenser, and should be carefully protected from cooling. A system of valves was accordingly introduced, which combined all these conditions, and were found in their practical working to be very satisfactory.

There were a few other points of practical importance which ought to be considered in the comparison of the Cornish with the compound-cylinder engine for pumping purposes. The Cornish engine was only single acting, and this entailed (for an engine of a given power) cumbersome size, great weight, and large expense,

as well as extra size and cost of engine-house. Moreover, it was slow in working, and irregular in action, which was considered a great disadvantage, when it was necessary to pump into iron mains; on the contrary, the compound-cylinder engine was double acting, smaller, less heavy, and less costly, and quick and regular in its working; and if with those advantages it could be made to realize an equal economy, its superiority appeared to be sufficiently proved.[1]

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[1] Note on the Theory of the Action of the Compound-cylinder Engine.

In investigating the principles of the double, or compound-cylinder engine, it will be convenient to assume that the length of stroke in both cylinders is the same, and that the pistons move simultaneously with equal velocity, as would be the case if both pistons were attached to the same point of the beam. In the general investigation also, the clearance passages must be omitted; for as their action and effect depend on the arrangement of the valves, they should be considered specially when required.

Let

a = area of small cylinder.
A = „ large „
L = length of stroke.
l = length of stroke passed over before the steam is cut off from the small cylinder.
P = total pressure of the steam per square unit in the small cylinder, before cut off. This is assumed constant through the space l.
p = pressure of imperfect vacuum in the large cylinder, per square unit.

Also let

x = any space passed over by the pistons, reckoned from the commencement of the stroke, and
y = joint effective pressure on the two pistons at the end of the portion of the stroke x.

The whole stroke divides itself naturally into two portions; first before, and secondly, after the steam is cut off in the small cylinder.

First; before the steam is cut off. Suppose the pistons descending—the pressure above the small piston will be uniform, and

$$= a\,\mathrm{P}.$$

The pressure under it will be variable, and will be the same, per square unit, as that above the large piston; to find the value of this it is necessary to consider what has taken place in the preceding stroke.

The steam of pressure P had first filled the small cylinder to a cubic content $= a\,l$; and this, at the end of the stroke, had expanded into a space $= a\,\mathrm{L}$.

When the pistons have performed any portion x of their stroke downwards, the space occupied by the expanding steam will be reduced by the descent of the small piston, and increased by the descent of the large one; *i. e.*, it would become

$$= a\,\mathrm{L} + (\mathrm{A} - a)\,x.$$

According, therefore, to Mariotte's law, which may be taken as sufficiently accurate for the purpose, the pressure of the steam flowing from the bottom of the small cylinder to the top of the large one, will be, after any portion x of the stroke has been passed over,

$$= \mathrm{P}\,\frac{a\,l}{a\,\mathrm{L} + (\mathrm{A} - a)\,x} \quad . \quad . \quad . \quad (\mathrm{I.})$$

And this, multiplied by a, will be the back pressure against the small piston.

Now, the downward or forward pressure upon the large piston will be the same as in Equation I., multiplied by A; and the force of the imperfect vacuum acting

Mr. J. E. M'Connell said, that he had conducted some experiments at the South Staffordshire Waterworks, in order to

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in a contrary direction, will be $= p\,\mathrm{A}$; so that, adding the effect of the two pistons together, we shall have

$$y = a\,\mathrm{P} + (\mathrm{A} - a)\frac{a\,\mathrm{P}\,l}{a\,\mathrm{L} + (\mathrm{A} - a)\,x} - \mathrm{A}\,p \quad . \quad . \quad . \quad \text{(II.)}$$

The work performed, therefore, during the portion l of the stroke, will be

$= \int_o^l y\,dx$, or

$$\mathrm{U}_1 = a\,\mathrm{P}\,l\left\{1 + \log\frac{a\,\mathrm{L} + (\mathrm{A} - a)\,l}{a\,\mathrm{L}}\right\} \mathrm{A}\,p\,l \quad . \quad . \quad . \quad \text{(III.)}$$

Secondly, after the steam is cut off from the small cylinder.

Here the forward pressure in the small cylinder is variable; for, after a length of stroke x, the volume of steam, which was formerly $= a\,l$, will be increased to $= a\,x$, and the pressure per square unit will be consequently diminished to

$$\mathrm{P}\frac{l}{x}.$$

So that the total forward pressure on the small piston will be

$$= a\,\mathrm{P}\frac{l}{x}.$$

But the back pressure on this, and the forward pressure on the large piston, will be found by the same rule as before; so that the total aggregate force on the two pistons, after the steam is cut off, will be

$$y = a\,\mathrm{P}\,\frac{l}{x} + (\mathrm{A} - a)\frac{a\,\mathrm{P}\,l}{a\,\mathrm{L} + (\mathrm{A} - a)\,x} - \mathrm{A}\,p \quad . \quad . \quad . \quad \text{(IV.)}$$

And the work during this latter portion of the stroke will be $= \int_e^{\mathrm{L}} y\,dx$, or

$$\mathrm{U}_2 = a\,\mathrm{P}\,l\log\frac{\mathrm{A}\,\mathrm{L}^2}{a\,\mathrm{L}\,l + (\mathrm{A} - a)\,l^2} - \mathrm{A}\,p\,(\mathrm{L} - l) \quad . \quad . \quad . \quad \text{(V.)}$$

Adding, therefore, Equations III. and V. together, the total motive work developed during an entire single stroke of the two pistons, will be

$$\mathrm{U} = a\,\mathrm{P}\,l\left\{1 + \log\frac{\mathrm{A}\,\mathrm{L}}{a\,l}\right\} - \mathrm{A}\,p\,\mathrm{L} \quad . \quad . \quad . \quad \text{(VI.)}$$

It may now be easily shown that the theoretical effect of the expansion is the same with the double- as with the single-cylinder engine.

In Equation VI. $\frac{\mathrm{A}\,\mathrm{L}}{a\,l}$ represents the extent of the expansion, or the number of times the steam is increased in volume, from the time it is cut off in the small cylinder to the end of its action in the large one. Making this $= \mathrm{E}$, so that $\mathrm{E}\,a\,l = \mathrm{A}\,\mathrm{L}$, and using the dimensions of the large cylinder, the result is the work done in a single stroke,

$$\mathrm{U} = \frac{\mathrm{A}\,\mathrm{L}\,\mathrm{P}}{\mathrm{E}}(1 + \log\mathrm{E}) - \mathrm{A}\,\mathrm{L}\,p \quad . \quad . \quad . \quad \text{(VII.)};$$

which is precisely the same expression as represents the work of steam used expansively in a single cylinder, whose area $= \mathrm{A}$, and length $= \mathrm{L}$; and in which the steam is cut off at $\frac{1}{\mathrm{E}}$ of the stroke;* the quantity of steam used, and the duty it performs, being in both cases alike.

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* *Vide* Pole on the "Cornish Pumping Engine." Note to Art. 204.

[The

determine what amount of duty in the engines would suffice for the requirements in view, and, he thought, a few particulars of

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The last equation also furnishes the proof of the second principle stated above, namely, that for a given initial pressure of steam, and degree of expansion, the power of the engine, measured by the work it will do each stroke, depends solely on the size (A L) of the large cylinder.

The cubical quantity of steam at pressure P, used to produce the work in Equation VII., is

$$= \frac{A\,L}{E};$$

from which the duty of the engine may be found in the usual way.

If the dimensions be all taken in feet, and the pressure in lbs. per square foot, and if N = number of single strokes per minute, then the theoretical horse power of the double cylinder engine will be

$$H = \frac{A\,L\,N}{33{,}000}\left\{\frac{P}{E}(1 + \log E) - p)\right\} \quad . \quad . \quad . \quad \text{(VIII.)}$$

The logarithms being the hyperbolic, or Napierian. It must be remarked, however, that the value of P used, must be the pressure of steam in the small cylinder before cut off, and not that in the boiler, which is generally much higher.

It is also possible now to demonstrate the principle before laid down, that, for an engine of a given power and degree of expansion, there is a point at which the steam may be cut off in the small cylinder, so that the excess of force at the commencement of the stroke may be a minimum.

Simplifying Equation II. by omitting the imperfect vacuum, and making $x = 0$, the aggregate force on the two pistons at the commencement of the stroke, is obtained,

$$y = P\left\{a + (A - a)\frac{l}{L}\right\}.$$

Let $\frac{l}{L}$, or the fraction of the stroke at which the steam is to be cut off, be represented by x, the independent variable. And let E represent the extent of the expansion, as before, which will be constant.

Then, since the power of the engine (measured by the size of the large cylinder) is also to be constant, a will be variable $= \frac{A}{E\,x}$; when the total initial force

$$= A\,P\left\{\frac{1}{E\,x} + x - \frac{1}{E}\right\} \quad . \quad . \quad . \quad \text{(IX.)}$$

which must be a minimum.

Treating this in the usual way, the simple result is arrived at, that the initial force, or blow, is at a minimum, when

$$x = \frac{1}{\sqrt{E}} \quad . \quad . \quad . \quad \text{(X.)}$$

that is, when the small cylinder is so proportioned to the large one, and to the proposed degree of expansion, that the fraction of the stroke where the steam is cut off shall be equal to the reciprocal of the square root of the degree of expansion to be used.

Substituting this value in Equation IX., the force at the commencement of the stroke will be

$$y = A\,P\left(\frac{2\sqrt{E} - 1}{E}\right) \quad . \quad . \quad . \quad \text{(XI.)}$$

[Whereas

those trials might be interesting. The engines were made by Messrs. James Watt and Co., and consisted of a pair of double-acting cylinders of 46 inches in diameter, and the length of stroke was 8 feet. He was not able to go through a lengthened series of investigations, and it was therefore agreed, that the trials should be carried on during a period of about eight hours. Operations were commenced at $\frac{1}{2}$ past 7 o'clock A.M. on April 5th, 1860, and the trial was continued till $\frac{1}{4}$ past 4 P.M. 33 cwt. of good Welsh coals were weighed out. The fires were, as nearly as possible, in the same state at the close of the trial as at the commencement, though there was perhaps not so much strength of fuel at the earlier part of the experiment, the combustion being more complete at the end than at the beginning. The result in itself was so good that the facts were worth considering.

The mean lift, as indicated by Bourdon's gauge, and registered every half-hour, was 277·64 + the mean level of the water in the well below the gauge = 54·74, so that the total lift was 332·38 feet. The four boilers were under steam, each having an absolute surface of 2,715 feet, and the steam pressure was $25\frac{1}{2}$ to 27 lbs: the bars were 28 and $28\frac{1}{4}$. The pumps were 18 inches diameter in the working barrels, with a length of stroke of 8 feet, having a capacity of 88·1 gallons, or 881 lbs. The number of strokes of the two engines during the period was 6,374. From these figures it would be found, that 112,210,781 lbs. were lifted one foot high by the consumption of 1 cwt. of coal.

The water was delivered into the Wednesbury reservoir, through a main of 24 inches for 5 miles; then through a main of 22 inches for 8 miles; and then through a main of 18 inches for $\frac{1}{2}$ a mile. In verification of the efficiency of the pumps, the reservoir was twice gauged most accurately, at 11 o'clock and at 3 o'clock, and the quantity delivered during that time was found to be 504,357 gallons. The quantity, according to the number of strokes regis-

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Whereas, in a single-cylinder engine of the same power and same economy, it will be simply

$$y = \mathrm{A\,P} \quad . \quad . \quad . \quad \text{(XII.)}$$

A comparison of which two equations, for any given case, will show the advantage of the double-cylinder engine.

The mean motive power or force, in either case, will be found by dividing the total work (Equation VII.) by the length of the stroke L,

$$= \frac{\mathrm{A\,P}}{\mathrm{E}}(1 + \log \mathrm{E}) \quad . \quad . \quad . \quad \text{(XIII.)}$$

The Table given in page 95 is calculated from these equations. The size of the small cylinder, in column 2, is given by the proportion

$$a = \frac{\mathrm{A}}{\mathrm{E}\,x} = \frac{\mathrm{A}}{\sqrt{\mathrm{E}}} \quad . \quad . \quad . \quad \text{(XIV.)}$$

The ordinates in the diagram illustrating this proposition are calculated from Equations II. and IV., omitting the imperfect vacuum.

tered by the counter and the capacity of the pump, should have been 535,824 gallons, the difference being a loss of about 5 per cent. The average consumption of coal per H.P. per hour was about 2 lbs.

No doubt, it would be said this was a large performance, as in fact it was; and he felt at the time, that there might have been errors in favour of the engine, though he did all he could to verify the facts. But assuming 1 cwt. of coal per furnace, which was more than, he thought, would be required, to represent the difference of the effective power for leaving off as compared with commencing—that would make 37 cwt., which would give about 100 millions of duty. He was quite of opinion that the engines did that, and more than that duty.

Mr. H. W. Blake wished to take the opportunity of making a few observations, generally, upon the class of engines which on the whole might be considered best suited to waterworks; and he would briefly allude to some of the different forms of engines which had on particular occasions been applied to that purpose.

Pumping engines might almost be divided into two entirely distinct classes—the single acting and the rotary. The single-acting engine, as originally made about forty-five years ago—before the Cornish engine came particularly into vogue—acted directly upon the water, and the pressure of steam rarely exceeded 4 lbs. or 5 lbs. per inch. The result obtained in that case, of course was not very high—not exceeding 30 millions or 35 millions. Then came the Cornish engine, as peculiarly applicable to the work of pumping from deep mines, with heavy pump-rods to be raised at each stroke; and the expansion being carried to a greater extent in those engines, a duty of 70 millions or 80 millions was obtained. Those results were considered startling, and the consequence was, that that class of engine was applied, almost immediately, to waterworks in general.

Now, though that class of engine was applicable, no doubt, to mines and to lifting heavy pump-rods, yet for waterworks the case was exceedingly different, and was open to many serious objections. Of course, the problem to be solved was, how to raise a given quantity of water with the least prime cost as regarded the engine and buildings, and, afterwards, with the least annual cost of working. The Cornish engine was liable, in the first place, in common with all single-acting engines, to the objection, that its large cylinders, large beams, and great mass of pumping weight, were only practically applied one way; while, in a double-acting engine, the same mass of materials would produce double the work. Then, the building required for a single-acting engine was costly as compared with the rotary engine; and there were several other minor points against the use of the single-acting

engine, except under peculiar circumstances. Nevertheless, it did become general, in consequence of the good results in the Cornish mines as compared with the rotary and direct-acting engines, in which the steam was not expanded, and the duty consequently was low. Since then, however, rotary engines had been applied at Newington, Lichfield, and other waterworks, and the results had shown that those engines possessed all the advantages of the single-acting engines, while the expense at the outset, for the house and engine was smaller. At Newington, in a trial of 19 days, a mean duty of 97 millions was attained, and that, added to the fact of a duty of from 100 millions to 112 millions, recorded at the South Staffordshire Waterworks, proved clearly, that even a single-cylinder rotative engine would produce results, not only equal, but superior to those generally obtained from the Cornish engine, and that expansion could be carried to a higher degree.

But the rotative engines might be divided into two classes—the single-cylinder engine, where the expansion was carried to a considerable extent, and the double-cylinder engine. With respect to the relative merits of the two, in the double cylinder there was a considerable disadvantage; there was no possibility of getting over the great loss which arose, in the passage of the steam from the upper side of one cylinder to the lower side of the other; and that would be perceived in all the diagrams. In the first place, there was the great drop in the pressure at the end of the stroke, arising from the clearance which of necessity existed (and which bore such a large proportion to the small cylinder) in the passages leading from the bottom of the small cylinder to the top of the large one. There was a gap between the figures taken from the one cylinder and the other, arising from the friction through the tortuous passages; from that defect arose, theoretically, a loss of 15 per cent. compared with the duty obtained from the single cylinder. His experience of the subject had therefore led him to the conclusion, that the most economical engine for ordinary waterworks, both as regarded first cost of machinery and building, and ultimate economy in working, was the simple high-pressure single cylinder, expansive and rotative engine.

Mr. Hawkshaw,—President,—inquired whether Mr. Blake could state the comparative cost of the rotative engine and the Cornish engine to perform the same duty.

Mr. Blake replied, that with a given sized cylinder, in the Cornish engine a speed of only about 100 feet per minute was got out of the single-action, but with the same sized cylinder, and the same materials applied to a double-acting engine, practically, double the work was obtained. Taking into consideration the cost of the house and the engine, he calculated there was a saving of one-third in the first cost to raise the same quantity of water by

the adoption of the single-cylinder rotative engine, instead of the Cornish engine.

Mr. HAWKSLEY, V.P., said, that in the Paper no comparison had been drawn between engines of different classes, its scope had been simply the characteristics of Cornish engines. However, the discussion had branched off into a comparison between the single power Cornish engine and the double powered crank engine. With regard to the Cornish engine, he was quite willing to admit its many advantages for pumping purposes, whenever the water had to be raised from a deep shaft, and a large amount of matter had to be put in motion at each stroke. But he did not admit its advantages in regard to its application in waterworks, where it was the intention to transmit the water, through a long main, into a reservoir. On the other hand, it was not at all proper to apply either a single-cylinder engine, or a double-cylinder crank engine, where the water had to be raised from a deep shaft, as frequently happened in the practice of waterworks engineers: and the reasons were obvious. In the case of a deep shaft, it was necessary to give all the rods time, as it was called, to settle; and after the descent to bring them to rest; and after rising to allow them to come again to rest and steady themselves, before the motion was communicated in the opposite direction. Now, that was not practicable with crank engines: the crank continued the motion of the machine: there was no time for the rods to come to rest, and the consequence was, either the pump work, or the engine was injured. But in the case of engine-pumping into a main, the great object was, to keep the water in steady, uniform motion, and that result was accomplished, undoubtedly, by the continuous action of the crank, when attached to a double-acting pump, with the employment of only a small air-vessel, to take off the slight variation of motion which arose in the pump, without communicating it to the column of water.

There was another disadvantage with regard to the Cornish engine, and that was, not, as had been favourably stated, that the Cornish engine only did half the work with the same quantity of load; but, that the crank engine with the same sized cylinder did three times the work, for not only was the steam passed on both sides of the piston, but the engine moved with one-half more velocity.

He did not agree with the statement, that the Cornish engine was as safe as the crank engine, because in consequence of the former being what was called a 'loose' engine, it was liable to the crashing kind of accident which the other was not liable to. The Cornish engine, therefore, required constant attention. That was a source of great expense, and was one of the

reasons why, in small waterworks, the Cornish engine could not be applied under circumstances in which its application was practicable —though not so usefully as another class—in large works. Besides, the Cornish engine had not the same advantage of expansion that the crank engine had, whether the steam was applied in a single cylinder, or in a double cylinder.

It was true, that more duty could be got out of a single cylinder with the same amount of expansion, than out of a double cylinder: but the engine was placed much in the same condition as the Cornish engine—there was an enormous pressure at the commencement of the stroke, and a small pressure at its termination. Hence solid foundations, strength of machinery, and weight of parts were required to deal with that high pressure. On the other hand, with double cylinders, there was not that violent pressure at the commencement of the stroke; there were smaller parts for the engine, and much lighter foundations were required; therefore, although theoretically, the single cylinder produced greater effect than the double cylinder, yet practically, taking into account the great expansion required and the expense of the coal employed, the double-cylinder engine was a better engine than that with the single cylinder.

One of the diagrams exhibited, on the vertical line, an enormous amount of pressure at the commencement of the stroke, and a minute pressure at the end of the stroke: and the curve, which was very beautiful, nearly following the true curve of expansion, showed that the mean pressure was moderate. It followed that heavy parts were required, in order to bear with that heavy pressure at the commencement of the stroke, and to get out of those heavy parts that amount of work which was represented by the mean of the diagram. That was not a judicious application of materials; whether it was a judicious application of steam, or not, was another question.

He would now point out the diagram of the double-cylinder engine; the small cylinder was only 18 inches in diameter, the large cylinder 31½ inches diameter, and the length of stroke in the large cylinder was 6 feet; that engine, though so small, was doing, with Welsh coal, a duty of 85 millions, and it had the weight so distributed, by the mode in which the steam operated, that the parts were all light, the foundations moderate, the building small, and all about it compact.

The result of his experience upon the matter was, that when raising water from a pit, or forcing water into a stand-pipe (always supposing a stand-pipe to be a proper appendage to a waterworks, which in most cases it was not), then, no doubt, the Cornish engine would work well, but it would perform best when pumping out of a deep pit, and when it had a large amount of

heavy rods to continue its action and diminish its initial velocity. In all other cases of waterworks, it was decidedly best to employ the crank engine: and it was only a matter of judgment as to particular conditions, whether the crank engine should have a single cylinder, or a double cylinder. In the case of dear coal he would employ the double cylinder; in the case of cheaper coal he would employ the single cylinder; and either not cut off the steam at all, or not much before it got to the end of the stroke. With the double cylinder he would use eight expansions; beyond that, so little was gained by the system of expanding steam, that it was not worth carrying it further.

He would observe, with respect to the loss which was experienced in engines of that description, that in a non-expansive condensing engine, a cubic foot of water would raise 3,000,000 pounds 1 foot high; but with steam of three atmospheres, or 45 lbs. steam, and expanded eight times, the whole power contained in a cubic foot of water was 12 million foot pounds, which was almost exactly 6 H.P.; that was to say, 6 H.P. might be got per hour constantly (theoretically) out of a foot of water with that particular engine. If Welsh coal were used, 1 cubic foot of water would be evaporated with 6 lbs. of coal, which was 1 lb. per H.P., but that engine consumed $2\frac{6}{10}$ths lbs. per H.P. What became of the remainder, and where could the engine be improved? He had been at some pains to ascertain where the losses were, and he found that, in round numbers, the condensation amounted to 10 per cent.: the leakage of valves and pistons amounted to another 10 per cent.: and by the spaces and clearance it amounted to nearly 20 per cent. If $2\frac{6}{10}$ths were multiplied by these $\frac{4}{10}$ths, $1\frac{4}{100}$ths lb. would be immediately explained; that was, out of the $2\frac{6}{10}$ths lbs. there was 1 lb., and a little more, of loss.

But that was not all; a most excellent vacuum was made, not in the condenser, but in the cylinder. The defect was $1\frac{3}{4}$ths in the cylinder over the average of the whole stroke. Then again, there was the resistance of the valves and pipes connecting the two cylinders together, which was indicated by a loss between the two lines, and averaged another pound; then there was the friction of the engine, which was about $2\frac{1}{4}$ lbs., and thus, as the pressure upon the engine was only about 15 lbs., there was one-third of the residue lost; but the residue was $1\frac{1}{2}$ lb. and one-third of that was the actual work done by the engine. It was easy to explain these losses, but not to prevent them. His opinion was, that it was not possible to make an engine of that class, using steam expanded eight times, that would do more than 100 millions of duty.

With regard to the question of duty, the experimental data were not to be relied upon, as a general rule. Every person acquainted

with Cornish engines and practice—and it equally applied to all other engines—knew that the duty was much coaxed. It was right to employ the best means when making a test, but the results were not working results ; and, at the end of twelve months, it was generally found, that the engine only realised a half, or three-fourths of the experimental duty.

As to the comparative cost of the engines, excellent first-class engines, upon the crank principle, could be bought and erected with all the pumps complete for about £45 per H.P. The house for the reception of those engines, as a rule, could be built at from £25 to £30 per H.P. The Cornish engine could not be purchased under £10 more per H.P., and at least that amount more per H.P. would be expended for the house. Then came the extra cost of foundations and other expenses incidental to the peculiarities of the Cornish engine. Therefore, he repeated, that while it was proper to apply the Cornish engine in a number of cases, where there was a large mass of inert matter to be put in motion, it was not proper to apply that sort of engine in other cases ; and he thought, from what he had gathered during the discussion, that that was the general opinion.

The subject, however, of the Paper, from which he had widely diverged, was the sort of record that should be kept of an engine to determine its duty and to realize a better economy of fuel. The simplest and best mode of ascertaining the performance of an engine was to learn what passed through the cylinder, and the temperature to which the cold water was raised. He found, in that particular engine, that the temperature of the waste water ought to be raised $16\frac{1}{2}^{\circ}$. The calculation was simple. It was actually raised 20°. There was a loss of unutilized steam of $3\frac{1}{2}^{\circ}$ out of 20°, equal to $\frac{1}{6}$th. In other words, the steam had passed the pistons and the valves, without performing work upon the pistons. Then there was another portion of the steam, which had done work by superheating. As the steam admitted into the cylinder became colder, it required to be superheated by the steam in the jacket, and in consequence, it expanded considerably, and did much more work than it otherwise would have done. But there was a great mistake, notwithstanding, about the economy of superheating, because, after all, the extra heat had to come out of the boiler. It was not heat gained in some unknown manner, but the steam, instead of being condensed in the cylinder, was condensed in the jacket. The true value of "jacketing" the cylinder, might be illustrated by the case of a single Cornish engine, supposed to be expanding seven times, or eight times. That engine, when first worked, made a full stroke of 8 feet, or 9 feet, but at the end of an hour and a half the stroke was only 7 feet 6 inches. The engine had then to be heated, to warm up the lower end of the cylinder,

and it worked to the full length of the stroke again; after that, it went on gradually decreasing inch by inch, till it got again to 7 feet 6 inches, and then the same operation had again to be gone through, to bring up the full stroke. He therefore believed, that there was no remarkable economy in superheating; but that the real value of the application of steam in the jacket was to keep the cylinder hot in one part, where high-pressure steam came in, and prevent it from becoming cool in the other part, where the low-pressure steam went out.

Mr. Alexander Fraser observed, through the Secretary, that it had been stated as an objection to the use of Cornish pumping engines for the water supply of towns, that the engine having to lift a weight, and the weight having to lift the water, it was necessary, in fact, to lift the whole of the water to the maximum height of the supply required; whereas the quantity of water to be pumped, and the level required to be reached, were constantly varying throughout the period of working. That objection would only apply to those cases in which the water was pumped directly from the works to the houses, without the intervention of a reservoir; but the practice had become general to supply the houses by means of a reservoir, into which the water was pumped. The head of water, or load on the engine, was then nearly constant, and, as Engineers when adopting crank engines usually employed a reservoir also, thereby equalizing the load on the engine, it did not appear how, as waterworks were usually arranged, one plan had any advantage over the other, in that respect.

It had also been asserted, that it would be more desirable, where the amount of work to be performed was liable to variation, to have several engines of small power, which might be set to work when required, than one engine of large power, which might only be called upon to exert its full power at certain intervals; but, it was found in practice, that the engines with cylinders of large areas did a better duty than those with small cylinders, the loss by friction and radiation of heat being less in proportion. In addition to which, the cost of attendance for a large engine was no more than for a small one; and as the piston of a Cornish engine travelled at the same speed, whether making two strokes per minute or twelve, a proper arrangement of the work to be done would enable the Cornish engine to meet the difficulty of a variable rate of pumping, more economically than the crank engine, which must work at a disadvantage when travelling at a slow speed.

Nor was the risk of accident greater with a Cornish engine than with a crank engine: the former was usually provided with a stand-pipe, having the top open, which effectually prevented the pressure in the mains exceeding a certain amount, and insured the safety of the engine, in case of breakages occurring to the mains;

which accidents were not so frequently caused by the working of the engines as might be supposed. The stand-pipe, in fact, caused a separation between the two, and the pause which took place between the strokes of a single-acting engine, allowed of a partial subsidence of the pressure before the next stroke took effect, the result being, that the mains were not actually so likely to be injured in this manner as, when fed by crank engines, with double-acting pumps and heavy fly-wheels; and if an accident of this nature really took place, the Cornish engine, not being encumbered with a fly-wheel, could, when properly attended to, be stopped instantly.

With respect to the excessive cost of Cornish, compared with other engines, it might be observed, that one of the chief causes of that excess had hitherto been the necessity of providing foundations for the cylinder, beam, and pumpwork, of great weight and strength; but that heavy item of expense had been considerably reduced in the direct-acting Cornish engines, introduced within the last few years into some of the London waterworks. In those engines the cylinders were placed vertically over the pumps, the piston rod working through the bottom of the cylinder; the air pump was worked by a wrought-iron half beam, and the economy of space was so great, that two engines could be accommodated in the same room that would be required for one beam engine. By that arrangement, the cost of the engine and engine house was considerably reduced; and, as the heavy beam and parallel motions were dispensed with, much greater safety from accident was the result, those members of the machine being the most liable to casualties. But, of course, economy in working expenses and greater durability would be sufficient reasons for the outlay of some additional capital when the engines were erected. With respect to durability, it was frequently found, that Cornish engines would work day and night for twenty years, without any repairs of importance.

At the Kew Bridge Station of the Grand Junction Water Company, there were five Cornish engines, three of which were usually worked by day, and two by night. The usual duty performed by those engines, which were all single-acting Cornish engines, was 73 millions with 1 cwt. of small coal, costing 13*s.* per ton, or 7 lbs. per nominal H.P. per hour. That was the ordinary duty maintained throughout the year. The consumption of coal at those works was at the rate of 4 lbs. per square foot of fire-grate surface per hour; but at the more recently constructed works of the same company at Campden Hill, Kensington, the consumption was at the rate, at the present time, of only $1\frac{1}{2}$ lb. per foot of grate surface per hour—that slow rate of combustion being arrived at by the use of a large number of boilers.

It had been maintained, that the pressure in the boilers being say

45 lbs. per inch, a pressure of steam in the cylinder of only 15 lbs. could be allowed consistently with safety, but that was not borne out in practice. It was true, that the average pressure on the piston throughout the stroke did not usually exceed 15 lbs., but the steam was admitted to the cylinder at the full pressure of the boilers; and, in order to insure that effect to the fullest extent, it was then the practice to employ large steam chests, and steam pipes of ample area, to prevent, as much as possible, loss of pressure by wire drawing; and the full pressure being let in, just when it was required to overcome the 'vis inertiæ' of the weight to be lifted, the mass was set in motion; the sudden blow given by the steam causing the piston to travel with such velocity, that the pressure was soon reduced; but by that time most of the work was done.

It had also been asserted, that for fear of banging or striking at the top, or bottom of the stroke, a certain space was left at either end of it, occupied by steam, which was, in fact, wasted. That objection, of course, applied most strongly, in the case of a single-acting engine, to the top of the cylinder, into which the steam was admitted, and that happened to be the end of the cylinder which was most nearly approached by the piston without risk of ill consequences; for when the steam entered the cylinder, the piston flew down with such velocity, that a certain margin at the bottom of the cylinder was desirable; but as the engine worked less rapidly out of doors, and in most cases slowly, there was no fear of the piston too closely approaching the cylinder cover, and consequently there was but little space wasted.

A great advantage presented itself in the single-acting Cornish engine, in the almost unlimited lead which could be given to the valves. After the steam had enabled the engine to make a stroke, the equilibrium valve was opened, while the weight of the pump carried the piston to the top of the stroke again; that valve was then closed, a little before the end of the stroke, so that a small portion of steam remained above the piston, and became compressed, keeping the steam end of the cylinder warm against the next admission of steam. The exhaust valve also being opened, shortly before the top steam valve, time was allowed for the formation of a more perfect vacuum under the piston, than would be the case if the exhaust valve and steam valve were opened at the same instant of time. Again, it was not, in practice, found a disadvantage for the piston to travel, and consequently the plunger of the pump to lift, with great velocity; as the use of the double-beat valve, or better still Husband's four-beat valve, enabled the pump to fill without difficulty, and it was desirable to have the suction valve so deep as always to be under water, and not to have to lift the water from a depth, up to the point of delivery.

In conclusion, if there were any advantages in slow combustion,

great speed of piston, durability, and freedom from accident, and a low rate of consumption of fuel, it might fairly be assumed, that the Cornish pumping engine was a machine well adapted to do the work required of it; and Engineers were quite justified in recommending its application to waterworks purposes.

Mr. HAWKSHAW,—President,—said, the interesting discussion which this Paper had elicited certainly related to one of the most important subjects to which the attention of Engineers could be directed—the improvement of the steam-engine. He hoped those Members whose avocations were more immediately connected with machinery of that character, would continue their inquiries, and endeavour eventually to invent a better engine than either the Cornish, or any other kind of engine. He thought, from the observations which had been made, that there were great difficulties in the way of that discovery. Where coal was cheap, men were not anxious to have a more perfect machine. It was with economy of coal as with everything else—much care was not generally taken of that which was acquired easily and at little expense. That difficulty would be surmounted as coal got dearer, which, as those who took a gloomy view of the coal question thought it might do, before very long. He hoped, however, that whether coal were cheap, or dear, an effort would be made on the part of the profession to produce the best machine possible.

November 24, and December 1 and 8, 1863.

JOHN HAWKSHAW, President,
in the Chair.

The discussion upon the Paper No. 1,043, "On the Duty of Cornish Pumping Engines," occupied the whole of these meetings, to the exclusion of any other subject.

The following Candidates were balloted for and duly elected on December 1st:—WILLIAM BELL, THOMAS OLINTHUS DONALDSON, and EDWARD ALEXANDER JEFFREYS, as Members; JOHN ORME ANDREWS, CHARLES WILLIAM ARCHIBALD, EDWARD HAMER CARBUTT, GEORGE HALLEN COTTAM, JOSEPH SCHRODER CROUCHER, WILLIAM ELLIOT, ROBERT FOGG, ALISTER FRASER, WILLIAM JERRY WALKER HEATH, GEORGE KILGOUR, and PETER PAUL MARSHALL, as Associates.

ANNUAL GENERAL MEETING.

December 15, 1863.

JOHN HAWKSHAW, President,
in the Chair.

Messrs. T. M. Smith, T. Marr Johnson, and C. B. Lane, were requested to act as Scrutineers of the Ballot, for the election of the President, Vice-Presidents, and other Members and Associates of Council for the ensuing year.

The list of the attendances of the Members of Council for the past year was read, and the Ballot was commenced; the Balloting Papers being sent for examination at intervals of fifteen minutes, in order to expedite the labours of the Scrutineers.

The Annual Report of the Council, on the proceedings of the Institution during the past year, was read.

Resolved,—That the Report of the Council be received and approved; and that it be referred to the Council, to be arranged for printing, and that it be circulated with the Minutes of Proceedings in the usual manner.

Resolved,—That the thanks of the Institution are due, and are presented to Messrs. F. J. Bramwell and John V. N. Bazalgette for the readiness with which they undertook the office of Auditors of Accounts, and for the clear statement they have laid before the Meeting; and that Messrs. John V. N. Bazalgette and T. Marr Johnson be requested to undertake the office of Auditors for the ensuing year.

The Telford and Watt Medals, and the Telford and Manby Premiums of Books, which had been awarded, were presented.

Resolved,—That the thanks of the Institution are justly due, and are presented to the Vice-Presidents and other Members of the Council, for their co-operation with the President, their constant attendance at the Meetings, and their zeal on behalf of the Institution.

Mr. M'Clean, Vice President, and Mr. Hawksley, Member of Council, returned thanks.

Resolved unanimously,—That the cordial thanks of the Meeting be given to Mr. Hawkshaw, President, for his strenuous efforts in the interests of the Institution, for his extraordinary attention to

the duties of his office, and for the urbanity he has at all times displayed in the Chair.

Mr. Hawkshaw, President, returned thanks.

Resolved unanimously,—That the cordial thanks of the Meeting be given to Mr. Charles Manby, the Honorary Secretary, and to Mr. James Forrest, the Secretary, for their constant zeal and devotion to the interests of the Institution, the ability displayed by them in the execution of their duties, and their attention to the individual wishes of the Members.

Mr. Manby and Mr. Forrest severally returned thanks.

The Ballot having been open more than an hour, the Scrutineers, after examining the papers, announced that the following gentlemen were duly elected to fill the several offices in the Council for the ensuing year:—

President.

JOHN ROBINSON M'CLEAN.

Vice-Presidents.

John Fowler.	Thomas Hawksley.
Charles Hutton Gregory.	John Scott Russell, F.L.S.

Other Members of Council.

Members.

Sir W.G.Armstrong,C.B.,FRS.	George Willoughby Hemans.
William Henry Barlow, F.R.S.	John Murray.
Nathaniel Beardmore.	George Robert Stephenson.
Joseph Cubitt.	Charles Vignoles, F.R.S.
Thomas Elliot Harrison.	Joseph Whitworth, F.R.S.

Associates.

Colonel Jervois, R.E., C.B.	Charles Waring.

Resolved,—That the thanks of the Meeting be given to Messrs. Smith, Johnson, and Lane, the Scrutineers, for the promptitude and efficiency with which they have performed the duties of their office, and that the ballot-papers be destroyed.

ANNUAL REPORT.

Session 1863-64.

In the interval that has elapsed since the last Annual General Meeting, it is gratifying to the Council to be able to state, that the progress of the Institution has been eminently satisfactory. The Papers read at the Meetings have been numerous and varied, the Meetings have been very fully attended, the Library has received considerable accessions, the number of Members has steadily increased, and the Funds are in a prosperous state. These are certain tests that the Institution continues to be appreciated by those in whose interest it was established, and lead to the conclusion that, so long as its affairs are conducted as they have hitherto been, similar support and countenance will be extended to it.

The Papers read during the past session were :—"The Railway System of Germany," by R. Crawford, (Assoc. Inst. C.E.); "The Hownes Gill Viaduct, on the Stockton and Darlington Railway," by W. Cudworth, (M. Inst. C.E.); "On the Use of the Timber of the Palmyra Palm in the Construction of Bridges," by H. Byrne, (M. Inst. C.E.); "On some of the Internal Disturbing Forces of Locomotive Engines," by A. W. Makinson, (M. Inst. C.E.); "On Railway Telegraphs, and the Application of Electricity to the Signalling and Working of Trains," by W. H. Preece, (Assoc. Inst. C.E.); "On the Woods used for Sleepers on the Madras Railway," by B. McMaster, (M. Inst. C.E.); "Description of the Drainage of the Borough of Dundee," by J. Fulton; "Description of the Sewerage and Drainage Works, at Newport, Monmouthshire," by A. Williams, (Assoc. Inst. C.E.); "American Timber Bridges," by J. R. Mosse, (M. Inst. C.E.); "On the Reconstruction of the Dinting and the Mottram Viaducts," by W. Fairbairn, (M. Inst. C.E.); "The Perennial and Flood Waters of the Upper Thames," by the Rev. J. C. Clutterbuck, M.A.; "Description of the Lydgate and of the Buckhorn Weston Railway Tunnels," by J. G. Fraser, (M. Inst. C.E.); "Public Works in Pernambuco, in the Empire of Brazil," by W. M.

Peniston, (M. Inst. C.E.); "Structures in the Sea, without Cofferdams; with a Description of the Works of the New Albert Harbour at Greenock," by D. Miller; "Description of the Line and Works of the Scinde Railway," by J. Brunton, (M. Inst. C.E.); "Account of the Cofferdam, the Syphons, and other works, constructed in consequence of the failure of the St. Germains' sluice of the Middle Level Drainage," by J. Hawkshaw, (President Inst. C.E.); "The Charing Cross Bridge," by H. Hayter, (M. Inst. C.E.); "American Iron Bridges," by Z. Colburn; "On the Communication between London and Dublin," by W. Watson, (Assoc. Inst. C.E.); and, "On the Manufacture of Duplicate Machines and Engines," by J. Fernie, (Assoc. Inst. C.E.).

This enumeration shows the variety of subjects which engage the attention of Engineers at the present day, and the extended area embraced within the operations of the members of the profession; for in almost all parts of the world, Public Works of magnitude are being prosecuted, chiefly under the direction of British Engineers, for facilitating intercourse, both for external and internal trade, and for the convenience of commerce.

The following Telford and Watt Medals, and Telford and Manby Premiums of Books, have been awarded to the Authors of some of these communications:—

1. A Telford Medal, and a Telford Premium, in Books, to John Brunton, M. Inst. C.E., for his "Description of the Line and Works of the Scinde Railway."
2. A Telford Medal, and a Telford Premium, in Books, to James Robert Mosse, M. Inst. C.E., for his Paper, "On American Timber Bridges."
3. A Telford Medal, and a Telford Premium, in Books, to Zerah Colburn, for his Paper, "On American Iron Bridges."
4. A Telford Medal, and a Telford Premium, in Books, to Harrison Hayter, M. Inst. C.E., for his Paper, "On the Charing Cross Bridge."
5. A Telford Premium, in Books, to William Michael Peniston, M. Inst. C.E., for his Paper, "On Public Works in Pernambuco, in the Empire of Brazil."
6. A Telford Premium, in Books, to William Henry Preece, Assoc. Inst. C.E., for his Paper, "On Railway Telegraphs, and the Application of Electricity to the Signalling and Working of Trains."
7. A Telford Premium, in Books, to Alexander Woodlands Makinson, M. Inst. C.E., for his Paper, "On some of the Internal Disturbing Forces of Locomotive Engines."
8. A Telford Premium, in Books, to Daniel Miller, for his Paper, "On Structures in the Sea, without Cofferdams; with a

Description of the Works of the New Albert Harbour at Greenock."

9. A Telford Premium, in Books, to Robert Crawford, Assoc. Inst. C.E.; for his Paper, "On the Railway System of Germany."
10. A Telford Premium, in Books, to William Cudworth, M. Inst. C E., for his Paper, "On the Hownes Gill Viaduct, on the Stockton and Darlington Railway."
11. A Telford Premium, in Books, to James Grant Fraser, M. Inst. C.E., for his Paper, "Description of the Lydgate and of the Buckhorn Weston Railway Tunnels."
12. A Watt Medal, and the Manby Premium, in Books, to John Fernie, Assoc. Inst. C.E., for his Paper, "On the Manufacture of Duplicate Machines and Engines."

The warmest thanks of the members are due to the President for his interesting "Account of the Cofferdam, the Syphons, and other works, constructed in consequence of the failure of the St. Germains' Sluice of the Middle Level Drainage," a communication which, from the Author's official position in the Institution, was not, it is almost needless to remark, considered in the adjudication of the Premiums.

The Scinde Railway, an account of the line and works of which was given by Mr. John Brunton, has been described as 'the neck of the funnel' of a system extending from Kurrachee, the natural port of the Punjâb and of Central Asia, along the route of the Indus Valley, and so onwards to Delhi, where a junction will ultimately be effected with the East Indian Railway, thus completing a great steam line connecting the Arabian Sea with the Bay of Bengal. The plan adopted for attracting labourers to this undertaking, and the average prices of the principal kinds of work, were given in detail. The geological and physical features of the country traversed by the line were next noticed, and then followed a description of the works themselves. Finally, the Author took occasion to remark, that the extension of railway communications into wild and uncivilized countries demanded from all grades of employés the exercise of more than ordinary observation, self-discipline, and energy, by which alone the respect of the native could be obtained, and his willing services be secured; thus converting the railway engineer into a pioneer of civilization and a missionary of science.

The account given by Mr. Mosse of different systems of construction of "American Timber Bridges" was very complete, and was a valuable addition to the records of the Institution, as affording illustrations of the most approved forms of such works, derived

from the experience which had been gained in those parts of America where timber was readily obtained, and was the only material practically available in a new and comparatively poor country, where the cost of more permanent structures could not be supported. In this respect American engineers had perhaps made a virtue of necessity ; but it was shown, in Mr. Colburn's Paper on "American Iron Bridges," that, within the last ten or twelve years, on all important lines in the States, iron truss bridges were gradually superseding those of timber, and several large metal structures on the 'Murphy-Whipple,' the 'Bollman,' and the 'Fink' systems were described. Some remarks were also made upon the strength of American iron, its high qualities being attributed to the purity of the ore and of the fuel employed in the manufacture.

Mr. Hayter's Paper on "The Charing Cross Bridge" was a description, in detail, of a large and important work, for carrying the line of the Charing Cross Railway,—an extension of the South Eastern system,—over the river Thames, to a central west-end terminus. The bridge, as is well known, occupies the site of the much-admired Suspension Bridge, for foot-passengers, erected some years previously from the designs of the late Mr. I. K. Brunel, the chains and ironwork of which are now being used in the completion of a somewhat similar work over the river Avon at Clifton. The magnitude of the Charing Cross Bridge may be gathered from the following particulars :—It consists of nine spans,—six of 154 feet each, and three of 100 feet each; the width of the bridge over the former openings being sufficient for four lines of way, and for a footpath on each side of 7 feet wide in the clear ; while over the latter this width is spread out towards the abutment in a fan shape, for the purpose of affording increased station accommodation. There are two main girders of wrought iron over the 154 feet openings, to which are suspended cross girders, also of wrought iron, for carrying the roadway. The total weight of wrought iron was 4,950 tons, and of cast iron 1,950 tons, and it was stated that the total cost, including the abutments, would be £180,000, or about £1 15*s.* per square foot of roadway.

In the Paper on "Public Works in Pernambuco, in the Empire of Brazil," by Mr. W. M. Peniston, it was stated that the object was to describe a few of the public works of one of the most extensive, productive, and least-known empires of the world. It was remarked that the absence of river navigation, the inefficiency and great cost of the public roads, and the horrible character of the common roads of the country, naturally led to the consideration of a railway. A line was proposed to extend throughout the entire length of the province, from Recife, the capital, to the Falls of

Paulo Affonço, on the Rio São Francisco, but at present only the section to the river Una had been executed. The country traversed by this section was said to present a great uniformity in its physical features. The works were then described, and details were given of their cost, as well as of the prices of materials, and of the wages of both native and foreign labour. The labour question, as being one of the most vital importance to the future of Brazil, was treated at considerable length, and the conclusion arrived at was, that for all the higher orders of work, foreigners must be imported.

Mr. Preece, whose Paper on "Railway Telegraphs, and the Application of Electricity to the Signalling and Working of Trains," led to so long a discussion, did not advocate the general and indiscriminate adoption of the telegraph, as a primary power, in the working of railways, but thought that in its secondary, or auxiliary character, its capacity was invaluable. The various systems in use on different lines were described, and it was urged that as no two lines having their termini in London employed the same system, while on some lines more than one method was in use, the necessity for discussion on this subject was apparent. Working lines by an interval of space in preference to an interval of time—the advantages and disadvantages of speaking telegraphs in connection with signalling apparatus—the necessity for assimilating the electric to the line signals—and the method of working single lines, were severally treated of.

The inquiry, "On Some of the Internal Disturbing Forces of Locomotive Engines," undertaken by Mr. Makinson, had chiefly reference to those generated by the reciprocating masses, as the piston, piston-rod, cross-head, half the weight of the connecting-rod, &c., the tendency of which, it was contended, was to produce sinuous motion. It was submitted that a single-cylinder engine would be free from this, that at high speeds there would be less fore-and-aft motion, and that the oscillation of the trains would be reduced. But in the course of the discussion it was urged, that the difficulty of starting a train with such an engine would be almost insurmountable, and the effect of having only a single central cylinder would be to raise the centre of gravity of the machine to an injurious extent.

The use of béton, or hydraulic concrete, as a constructive material, when deposited in a liquid state and allowed to set under water, brought forward by Mr. D. Miller in his Paper on "Structures in the Sea, without Cofferdams," was exemplified in his "Description of the works of the New Albert Harbour at Greenock," in the design of which the walls, under low water, consisted of a combination of cast-iron guide piles in the front, with a continuous stone facing,

slid down over and enclosing these piles, timber bearing piles being used in the body of the walls where required, and concrete backing being deposited in a soft state—the upper part of the walls being built of masonry in the ordinary way. The application of this system to the construction of Breakwaters and Harbours of Refuge was then noticed,—reference being made to the principal modes of construction hitherto adopted, and to the peculiar phenomena by which such structures were affected,—as well as to the construction of the works under low-water of marine fortifications, piers, quay-walls, lighthouses, &c. It was urged that such a system must lead to economy, combined with strength and durability, facility and rapidity of execution, and adaptability to situations where the present modes of construction would be inapplicable.

The rapid extension of railways in Germany might be gathered from this, that while at the close of the year 1835 there were only 4 miles of railway properly so called, at the end of 1861, a total of 8,866 miles, of which nearly one-fourth was provided with two lines of rails, had been constructed, at an average cost of £16,400 per mile. Mr. Crawford, in his account of "The Railway System of Germany," referred to "The Association of Government Railway Directions," which was established in the year 1847, and stated that this body issued a code of laws upon all points usually involved in the construction and working of railways. Some of the principal structures, as viaducts and bridges, both of stone and of wrought iron, were then described.

In the course of the discussion it was considered, that the principles which characterized the German system of railways were, the simplification of the permanent way and the perfection of their statistics; but it was believed that the average expenses per train mile were less in Great Britain than in Germany, or indeed on the continent generally.

"The Hownes Gill Viaduct, on the Stockton and Darlington Railway," was stated by Mr. Cudworth to be 730 feet in length, and 162 feet in height, at the deepest part of the Gill. It consisted of twelve semicircular arches, each 50 feet span and 14 feet in length, and was built of firebrick, set in hydraulic mortar, with the exception of the arches, which were in cement, at a cost of £15,716. Regarding the viaduct as an unpierced solid, its contents would amount to 61,910 cubic yards, and its cost would be 5 shillings and 1 penny per cubic yard. The question of the relative cost of brick and iron viaducts was then alluded to, by a comparison of the above work with the Beelah and the Deepdale iron viaducts on the South Durham and Lancashire Railway, and it was thought that, in the situation in question, brick would ultimately be the cheaper material; although in inaccessible districts

not yielding suitable building materials, or where the foundations were doubtful, iron might be selected.

Mr. Fraser proposed to supply, what had frequently been remarked in the Institution as a desideratum, particulars as to the construction of several tunnels on which he had been engaged, in his "Description of the Lydgate and of the Buckhorn Weston Railway Tunnels." This he supplemented by a summary of the cost of other works of a similar kind, carried out under the direction of Messrs. Locke and Errington, which might be taken to some extent as indicating the relative expense of piercing different strata.

The last Paper of the session, "On the Manufacture of Duplicate Machines and Engines," by Mr. Fernie, referred to the application, in the workshops of the Midland Railway, at Derby, of the system of end measurement with a gravity piece, introduced by Mr. Whitworth, for obtaining accuracy and uniformity. The advantages claimed were, economy in manufacture, greater excellence in workmanship, and a perfect system of duplicates, whereby the parts became interchangeable—a matter of considerable importance in all locomotive machines, and especially so in the case of Indian and Colonial Railways.

Many of the Papers read during the last two Sessions have, at the request of the Authors, been issued already in a separate form, so that the Volumes XXI. and XXII. of the Minutes of Proceedings for the Sessions 1861—62 and 1862—63 may be said to be completed, and will be promptly issued. An Index to the series from Vol. I. to XX. inclusive, is in hand, and though it is a task involving considerable labour, it has already advanced, and is in type, up to the letter F, while the MS. has proceeded considerably further.

Numerous applications having been made for completing the series of volumes of Minutes of Proceedings, of which some of the earlier numbers were out of print, the Council have determined to reprint such portions as are most needed, in order to be enabled to supply this evident want, and with the view of enabling the members to obtain complete sets at cost price.

The Annual Dinner this year must, like its predecessor, be regarded as a complete success; and it is flattering to the Institution and to the profession generally, that on both occasions there appeared as guests many distinguished men who expressed themselves in gratifying terms as to the Members of the Society.

The tabular statement of the transfers, elections, deceases, and resignations of Members of all classes during the years 1861-62 and 1862-63, taking into consideration the names which have been erased from the Register, appears thus:—

—	Honorary Members.	Members.	Associates.	Graduates.	Annual Increase.
1861-62.					
Transferred to Members . .	..	..	7	..	
Elections	..	35	37	..	73 − 18 = 55
Restored to the List . . .	..	1	..	..	
Deceases	2	7	6	1	18
Resignations	..	..	2	..	
1862-63.					
Transferred to Members . .	..	..	5	1	
Elections	..	25	49	..	74 − 34 = 40
Deceases	2	9	15	..	34
Resignations	..	1	4	..	
Erased from the Register . .	..	..	3	..	
Members of all Classes on the Books, November 30, 1863.	18	426	587	9	= 1,040

This represents an increase of 4 per cent. in the last twelve months, and of 39 per cent. in the last ten years. During this period of ten years the number of Members has increased to a greater extent than the Associates; for whereas the numbers of these classes on the 30th of November 1853 were 259 and 441, respectively, or in the proportion of 1 to 1·7, on the 30th November last these numbers were 426 and 587, or as 1 to 1·4.

If the Honorary Members and Graduates are omitted from the calculation, the annual increase of Members and Associates stands thus:—

Years.	Members Elected.	Associates Elected.	Total Elected.	Deceases, Resignations, and Erasures.	Effective Increase.
1858	11	25	36	13	23
1859	16	41	57	20	37
1860	23	39	62	25	37
1861	24	45	69	49	20
1862	35	37	72	15	57
1863	25	49	74	32	42

From this it appears that the effective increase during the last twelve months has been 42, as against 35, the average of the five preceding years.

The following Member and Associates having tendered their resignations, have been permitted to retire from the Institution:—Richard Vardon, Member; Alfred Charles Hobbs, Captain Donatus O'Brien, Daniel Thwaites, and William Locock Webb, Associates.

The deceases during the past year have been:—John Singleton

Copley, Lord Lyndhurst, and William Tooke, Honorary Members; Thomas Evans Blackwell, William Clegram, Richard Carden Despard, James Fenton, Joshua Field, Joseph Glynn, Mark Jones, William Lewin, and Captain William Scarth Moorsom, Members; Beriah Botfield, M.P., Alexander Bremner, Alexander Brodie Cochrane, William Coulthard, William Cubitt, M.P., William Dunlop, Charles Michael Jopling, Francis Morton, Geddie Pearse, Apsley Pellatt, William Rigby, Charles William Scott, James Sherriffs, Admiral Washington, and William Richard Whitmore, Associates.

The Memoirs of some of our late friends will be found in the Appendix to this Volume.

It will be observed, with deep regret, that while the Institution has lost many useful and able Members, there is included in the list one whose memory must ever be regarded with the liveliest interest;—for to Mr. Joshua Field, to whom allusion is made, is due, in no small degree, the existence of this Institution. It was about the year 1816 that Mr. Henry Robinson Palmer, who was then articled to Mr. Bryan Donkin, first suggested to Mr. Field the idea of forming a Society of young engineers, for their mutual improvement in mechanical and engineering science; and it was no doubt owing to Mr. Field's influence that Mr. William Nicholson Maudslay became the third who associated in this cause. These were shortly joined by five others, Mr. James Jones, Mr. Charles Collinge, Mr. James Ashwell, Mr. Thomas Maudslay, and Mr. John T. Lethbridge; and when the Institution was constituted on the 2nd of January, 1818, it comprised only these eight members, and it so remained until the following year, when the number was increased by three. From that time the numbers have steadily increased—the first great impetus being the acceptance of the office of President, in 1820, by Thomas Telford, under whose fostering hand the Institution grew rapidly in importance, and eventually acquired its present permanent position among the scientific societies of the Metropolis.

The amount of arrears of subscriptions for 1863, still remaining due on November 30th, is—

	£.	s.	d.	£.	s.	d.
From Members of all classes, residing abroad .	66	13	6			
From Members of all classes, residing in the United Kingdom	185	6	6			
				252	0	0

The amount of arrears for the years 1861 and 1862 is—

From Members of all classes, residing abroad .	36	4	6			
From Members of all classes, residing in the United Kingdom	109	4	0			
				145	8	6
Total				£397	8	6

This is less than at the date of the last Report, although it might have been anticipated to be subject to augmentation as the number of members increased.

The abstract of receipts and expenditure, as prepared by the Auditors, shows that the income, from all sources, during the twelve months from the 1st of December, 1862, to the 30th of November, 1863, was £3,974. 17*s*. 1*d*., while the payments in the same period only amounted to £2,740. 8*s*. 11*d*., leaving a balance of £1,234. 8*s*. 2*d*. Of this balance, a sum of £1,000 has been invested in the purchase of London and North Western Railway Four per Cent. Debenture Stock. During the last ten years the income from Subscriptions and Fees alone has increased from £2,013. 12*s*. to £3,215. 1*s*. 6*d*., or about 60 per cent., while the actual receipts from all sources were at the two periods £2,113. 11*s*. 6*d*. and £3,974. 17*s*. 1*d*., showing an increase of about 88 per cent. The expenditure within the same period has been fluctuating, being influenced by the amounts paid in each year on account of printing the Minutes of Proceedings; but it may be safely asserted that it has not increased in anything like the same proportion, as is shown by the investment during the last five years of a gross sum of £3,500 out of the general funds, besides making a repayment of £1,669. 8*s*. 6*d*., to the Telford Fund, on account of unexpended dividends.

The realized funds in the hands of the Institution, apart from the value of the lease of the premises, of the furniture, the books in the library, the stock of Transactions and of Minutes of Proceedings, and the arrears of subscriptions, are as follows:—

I. General Funds.

	£.	s.	d.	£.	s.	d.
1. Stephenson Bequest—North Eastern Railway Company Four per Cent. Debenture Stock	2,000	0	0			
2. Miller Bequest—Reduced Three per Cent. Consols	2,133	6	8			
3. Errington Bequest—Great Northern Railway Company Four per Cent. Debenture Stock	1,000	0	0			
4. Institution Investments—Great Eastern Railway Company, Norfolk Four per Cent. Debenture Stock	2,000	0	0			
„ Great Northern ditto	500	0	0			
„ London and North Western ditto	1,000	0	0			
				3,500	0	0
5. Cash in the hands of the Treasurer	666	17	11			
„ „ Secretary	56	16	1			
				723	14	0
						9 357 0 8

II. Building Fund.

	£.	s.	d.	£.	s.	d.
1. Great Northern Railway Company Four per Cent. Debenture Stock	500	0	0			
2. London and North Western ditto	500	0	0			
3. On Deposit at Union Bank	322	2	11			
						1,322 2 11

III. Trust Funds.

1. Telford Fund—Three per Cent. Consols .	2,551	15	10			
„ Three per Cent. Annuities .	2,342	17	1			
				4,894	12	11
„ Balance of Dividends, not yet expended in Annual Premiums, standing in Three per Cent. Reduced Annuities				1,775	19	8
2. Manby Donation—Great Eastern Railway Company, Norfolk, Five per Cent. Preference Stock				200	0	0
3. Miller Fund—Lancashire and Yorkshire Railway Company Four per Cent. Debenture Stock	2,000	0	0			
„ Great Eastern Railway Company, Norfolk, ditto	1,100	0	0			
				3,100	0	0
Total				£9,970	12	7

These three several funds amount in the gross to £20,649. 16*s.* 2*d.*, as against £19,040. 12*s.* 1*d.* at the same period last year

In the balloting list the name of Mr. John Robinson M'Clean, the senior Vice-President, is proposed as President, to succeed Mr. Hawkshaw, whose second year of tenure of office expires. Mr. T. Hawksley is proposed for the vacancy among the Vice-Presidents; and the names of Messrs. J. Abernethy, W. H. Barlow, and J. Brunlees, as Members, and of Messrs. J. Aird, Jun., A. Ogilvie, C. Waring, and Colonel Jervois, C.B., R.E., Associates, are added to complete the number required by the by-laws.

The Institution is now about to enter upon the forty-seventh year of its existence. It remains for the present Members to emulate the example of those who have preceded them, and to sustain the high character for usefulness which the Institution has always enjoyed.

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS.

Dr.	£.	*s.*	*d.*	£.	*s.*	*d.*
To Balance in the hands of the Treasurer				456	8	2
— Balance in the hands of the Secretary				32	17	8
— Subscriptions and Fees :—						
Arrears	255	13	0			
Current	2,593	10	0			
Subscriptions, 1864 (in advance)	14	3	6			
Fees	236	5	0			
Life	115	10	0			
				3,215	1	6
— Publication Fund				53	2	6
— Council Fund				50	0	0
— Publications :—Sale of Transactions				52	17	0
— Telford Fund :—						
Dividends—1 Year, on £2,551. 15*s.* 10*d.*, Three per Cent. Reduced Consols	74	0	1			
Ditto, 1 Year, on £2,342. 17*s.* 1*d.*, Three per Cent. Reduced Annuities	67	18	10			
Ditto, 1 Year, on £1,775. 19*s.* 8*d.*, Three per Cent. Reduced Annuities	51	9	11			
				193	8	10
— Manby Premium :—						
Dividends, 1 Year, on £200, Great Eastern Railway Company, Norfolk, Five per Cent. Debenture Stock				9	12	11
— Stephenson Bequest :—						
Dividends, 1 Year, on £2,000, North Eastern Railway Company Four per Cent. Debenture Stock				77	3	4
— Miller Fund :—						
Dividends, 1 Year, on £2,000, Lancashire and Yorkshire Railway Company Four per Cent. Debenture Stock	77	3	4			
Ditto, 1 Year, on £1,100, Great Eastern Railway Company, Norfolk, Four per Cent. Debenture Stock	42	9	11			
				119	13	3
— Miller Bequest :—						
Dividends, 1 Year, on £2,133. 6*s.* 8*d.* Three per Cent. Reduced Annuities				61	17	5
— Errington Bequest .—						
Dividends, 1 Year, on £1,000, Great Northern Railway Company Four per Cent. Debenture Stock				38	11	7
— Institution Investments :—						
Dividends, 1 Year, on £2,000, Great Eastern Railway Company, Norfolk, Four per Cent. Debenture Stock	77	5	3			
Ditto, ditto, on £500, Great Northern Railway Company Four per Cent. Debenture Stock	19	5	9			
Ditto, 64 days on £1,000, London and North Western Railway Company Four per Cent. Debenture Stock	6	17	9			
				103	8	9
				£4,464	2	11

from the 1ST DEC., 1862, *to the* 30TH NOV., 1863.

PAYMENTS.

Cr.	£.	*s.*	*d.*	£.	*s.*	*d.*
By House, Great George Street:—						
Rent	360	18	0			
Rates and Taxes	46	6	10			
Insurance	18	19	9			
				426	4	7
— Salaries				500	0	0
— Clerks, Messengers, and Housekeeper				254	7	0
— Wages of old Messenger, while in hospital				52	0	0
— Postage and Parcels:—						
Postage	32	6	0			
Parcels	0	16	11			
				33	2	11
— Stationery, Engraving, Printing Cards, Circulars, &c.				67	4	2
— Coals, Candles, Oil, and Gas:—						
Coals	16	10	0			
Oil	2	1	0			
Gas	32	1	9			
				50	12	9
— Tea and Coffee				26	15	11
— Library:—						
Books	40	12	10			
Periodicals	20	5	10			
				60	18	8
— Publication, Minutes of Proceedings				971	12	2
— Telford Premiums				36	13	4
— Council Premiums				32	8	1
— Watt Medal				2	1	0
— Stephenson Prize				26	5	0
— Miller Prizes				31	10	0
— Manby Premium				12	5	2
— Diplomas				17	2	4
— Manuscripts, Original Papers, and Drawings				1	12	2
— Winding and Repairing Clocks				1	10	0
— Annual Dinner				57	19	5
— Incidental Expenses:—						
Christmas Gifts	2	1	0			
Illumination, March 10th, 1863	12	0	0			
Occasional Assistance	4	10	5			
Assistance at Meetings	12	6	0			
Beating Carpets, etc.	3	1	6			
Household Utensils, Repairs, and Expenses	44	5	4			
				78	4	3
				2,740	8	11
— London and North Western Railway Company Debenture Stock				1,000	0	0
— Balance of Petty Cash, Dec. 1, 1863, in the hands of the Secretary				56	16	1
— Balance in the hands of the Treasurer				666	17	11
				£4,464	2	11

Examined and compared the above Account with the Vouchers and the Cash Book, and find this account to be correct, leaving a Balance in the hands of the Treasurer of Six Hundred and Sixty-six Pounds, Seventeen Shillings, and Eleven Pence.—Nov. 30th, 1863.

(Signed) F. J. BRAMWELL, JOHN V. N. BAZALGETTE, } *Auditors.*
JAMES FORREST, *Secretary.*

December 12th, 1863.

PREMIUMS AWARDED.

Session, 1862-63.

The Council of the Institution of Civil Engineers have awarded the following Premiums:—

1. A Telford Medal, and a Telford Premium, in Books, to John Brunton, M. Inst. C.E., for his "Description of the Line and Works of the Scinde Railway."
2. A Telford Medal, and a Telford Premium, in Books, to James Robert Mosse, M. Inst. C.E., for his Paper on "American Timber Bridges."
3. A Telford Medal, and a Telford Premium, in Books, to Zerah Colburn, for his Paper on "American Iron Bridges."
4. A Telford Medal, and a Telford Premium, in Books, to Harrison Hayter, M. Inst. C.E., for his Paper on "The Charing Cross Bridge."
5. A Telford Premium, in Books, to William Michael Peniston, M. Inst. C.E., for his Paper on "Public Works in Pernambuco, in the Empire of Brazil."
6. A Telford Premium, in Books, to William Henry Preece, Assoc. Inst. C.E., for his Paper "On Railway Telegraphs, and the Application of Electricity to the Signalling and Working of Trains."
7. A Telford Premium, in Books, to Alexander Woodlands Makinson, M. Inst. C.E., for his Paper "On some of the Internal Disturbing Forces of Locomotive Engines."
8. A Telford Premium, in Books, to Daniel Miller, for his Paper on "Structures in the Sea, without Cofferdams; with a Description of the Works of the New Albert Harbour at Greenock."
9. A Telford Premium, in Books, to Robert Crawford, Assoc. Inst. C.E., for his Paper on "The Railway System of Germany."
10. A Telford Premium, in Books, to William Cudworth, M. Inst. C.E., for his Paper on "The Hownes Gill Viaduct, on the Stockton and Darlington Railway."

11. A Telford Premium, in Books, to James Grant Fraser, M. Inst. C.E., for his Paper, "Description of the Lydgate and of the Buckhorn Weston Railway Tunnels."
12. A Watt Medal, and the Manby Premium, in Books, to John Fernie, Assoc. Inst. C.E., for his Paper "On the Manufacture of Duplicate Machines and Engines."

SUBJECTS FOR PREMIUMS,

Session, 1863-64.

The Council of the Institution of Civil Engineers invite communications on the Subjects comprised in the following list, as well as upon others; such as, 1, Authentic Details of the Progress of any Work in Civil Engineering, as far as absolutely executed (Smeaton's Account of the Edystone Lighthouse may be taken as an example); 2. Descriptions of Engines and Machines of various kinds; or, 3. Practical Essays on Subjects connected with Engineering, as, for instance, Metallurgy. For approved Original Communications on these, or other subjects, the Council will be prepared to award the Premiums arising out of special funds devoted for the purpose.

1. On the Decay of Materials in Tropical Climates, and the methods employed for arresting and preventing it.
2. On the Theory of Metal and Timber Arches.
3. On the Theory and details of Construction of Wrought Iron Girder Bridges.
4. On Land-slips, with the best means of preventing, or arresting them, with examples.
5. On the Pressure of Earth on Tunnels, and the conditions which limit its amount.
6. On the Theory and Practice of Artesian Well-boring, and of sinking large shafts, as now practised on the Continent.
7. On the results of contrivances for facilitating the Driving of Tunnels, or Drifts in Rock.
8. On the Principles to be observed in laying out lines of Railway through mountainous countries, with examples of their application in the Alps, the Pyrenees, the Indian Ghauts, the Rocky Mountains of America, and similar cases.
9. On the best means of preserving Railways in Alpine countries from interruptions from snow.
10. On the Results of recent experience in Iron Permanent Way.
11. On the Principles to be observed in the designing and arrangement of Terminal and other Railway Stations, Repairing Shops, Engine-sheds, &c., with reference to the traffic and the rolling stock.

12. On Railway Ferries, or the Transmission of Railway Trains entire across Rivers, Estuaries, &c.
13. On Locomotive Engines for ascending Steep Inclines, especially when in combination with sharp curves, on Railways.
14. On the Working of Locomotive Engines in Long Tunnels, with frequent stations.
15. On the Results of the Application of Giffard's Injector to the Boilers of Locomotive and other Engines.
16. On the Working Expenses of Railways, and the influence on these of the original design and construction.
17. On the Results of a series of observations on the Flow of Water from the Ground, in any large district; with accurately-recorded Rain-Gauge Registries, in the same locality, for a period of not less than twelve months.
18. On the Construction of Catch-water Reservoirs in Mountain Districts, for the supply of Towns, or for manufacturing purposes.
19. Accounts of existing Waterworks; including the source of supply, a description of the different modes of collecting and filtering, the distribution throughout the streets of Towns, and the general practical results.
20. On the Best Means of Improving the Water Supply of the Metropolis.
21. On the Structural Details, and the Results in Use, of Apparatus for the Filtration of large volumes of water.
22. On the Drainage and Sewerage of large Towns; exemplified by accounts of the systems at present pursued, with regard to the level and position of the outfall, the form, dimensions, and material of the sewers, the prevention of emanations from them, the arrangements for connecting the house drains with the public sewers, the best means of limiting the contamination of rivers from the sewage discharged into them, and the disposal of the sewage, whether in a liquid form, as irrigation, or in a solid form, after deodorisation.
23. On the Results of the Employment of Steam Power on Canals, and of other measures for the Improvement of Canals as a means of conveyance for heavy traffic.
24. On Iron Paving, and a comparison of the Results attained by it, and by stone block paving, &c.
25. A History of any Fresh Water Channel, Tidal River, or Estuary,—accompanied by plans and longitudinal and cross sections,—including notices of any works which may have been executed upon it, and of the effects of the works; particularly of the relative value of Tidal and Fresh Water, and of the effect of Enclosures from the Tidal Area upon

the general regime, of Sluicing where applied to the improvement of the entrance or the removal of a Bar, and of Groynes, or Parallel Training Walls. Also, of Dredging, with a description of the Machinery employed, and the cost of raising and depositing the material.

26. On the Results of a Series of Observations, illustrative of the modifications which the tidal wave undergoes in its passage up and down a river, or estuary.
27. On the Construction of Tidal, or other Dams, in a constant, or variable depth of water; and on the use of wrought iron in their construction.
28. A History of any Harbour, or Dock, including the reasons for selecting the site, the mode of construction adopted, and the subsidiary works for the convenience of shipping, and for commercial purposes, with the cost, &c.
29. On Graving Docks and mechanical arrangements having a similar object, with the conditions determining their relative applicability in particular cases, as dependent on the rise of tide, the depth of water, and other circumstances.
30. On the Arrangement and Construction of Floating Landing-Stages, for passenger and other traffic, with existing examples.
31. On the different systems of Swing, Lifting, and other opening Bridges, with existing examples.
32. On the Construction of Lighthouses, their Machinery and Lighting Apparatus; with notices of the methods in use for distinguishing the different Lights.
33. On the Measure of Resistance to Steam Vessels at high Velocities.
34. On the results of the use of Tubular Boilers, and of Steam at an increased pressure, with, or without superheating, for Marine Engines, noticing particularly the difference in weight and in speed, in proportion to the Horse Power and the Tonnage.
35. On the relative advantages of the Principle of Expansion, as applied in the Single long-stroke Cylinder Engine, in the Double Cylinder Engine, and in the Three Cylinder Engine; and on the adaptation of the two latter to marine purposes.
36. On the Principles and Varieties of Construction of Blast Engines, with British and Foreign examples.
37. On the best description of Steam Fire Engines, and their power and efficiency, as compared with ordinary hand Fire Engines.
38. On the construction of, and the comparative duty performed by, modern Pumping Engines for raising Water, for the

Supply of Towns, or for the Drainage of Mines; noticing in the latter case, the depth and length of the underground workings, the height of the surface above the sea, the geological formation, the contiguity of streams, &c.

39. On Turbines and other Water Motors of a similar character; and their construction and performance, in comparison with Water-wheels.
40. On the present systems of Smelting Iron Ores; and on the conversion of cast-iron into the malleable state, and of the manufacture of iron generally, comprising the distribution and management of Iron Works.
41. On the Manufacture of Iron for Rails and Wheel Tires, having special reference to the increased capability of resisting lamination and abrasion; and accounts of the Machinery required for rolling heavy Rails, Shafts, and bars of Iron of large sectional area.
42. On the Manufacture of large Masses of Iron for the purposes of Warfare, as Armour Plates, &c.
43. On the Construction of Rifled and Breech-loading Artillery; and on the Initial Velocity, Range and Penetration of Rifled Projectiles, and the influence of Atmospheric Resistance.
44. On the use of Steel Bars and Plates in Engine-work and Machinery, for Boilers and for Ship-building, as well as for Bridges.
45. On the Use of Steel in the Construction of Locomotive Engines, especially with reference to durability and the cost of repairs, in tires and cranked axles, as compared with Iron of acknowledged good quality.
46. On the Bessemer and other processes of Steel-making; on the present state of the Steel Manufacture on the Continent of Europe; and on the employment of castings in Steel for Railway Wheels and other objects.
47. On the safe working strength of Iron and Steel, including the results of experiments on the Elastic Limit of long bars of Iron, and on the rate of decay by rusting, &c., and under prolonged strains.
48. On the Transmission of Electrical Signals through Submarine Cables.
49. On the present relative position of English and Continental Engineering Manufactories, especially with reference to their comparative positions in respect of the cost, and the character of the work produced.
50. Memoirs and Accounts of the Works and Inventions of any of the following Engineers:—Sir Hugh Middleton, Arthur Woolf, Jonathan Hornblower, Richard Trevithick,

William Murdoch (of Soho), Alexander Nimmo, and John Rennie.

Original Papers, Reports, or Designs, of these, or other eminent individuals, are particularly valuable for the Library of the Institution.

The competition for Premiums is not confined to Members, or Associates of the Institution, but is equally open to all persons, whether Natives or Foreigners.

The Council will not consider themselves bound to award any Premium, should the Communication not be of adequate merit; but they will award more than one Premium, should there be several Communications on the same subject deserving this mark of distinction.

The Communications must be forwarded, on or before the 1st of February, 1864, to the house of the Institution, No. 25, Great George Street, Westminster, S.W., where copies of this Paper, and any further information may be obtained.

CHARLES MANBY, *Honorary Secretary.*
JAMES FORREST, *Secretary.*

25, *Great George Street, Westminster, S.W.,*
August, 1863.

NOTICE.

It has frequently occurred, that in Papers which have been considered deserving of being read and published, and have even had Premiums awarded to them, the Authors may have advanced somewhat doubtful theories, or may have arrived at conclusions at variance with received opinions. The Council would, therefore, emphatically repeat, that the Institution must not, as a body, be considered responsible for the facts and opinions advanced in the Papers, or in the consequent Discussions; and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the discussion and the inquiry; but that such notice, or award, must not be considered as any expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

EXTRACTS FROM THE MINUTES OF COUNCIL, FEB. 23rd, 1835.

"The principal Subjects for which Premiums will be given are:—

"1st. Descriptions, accompanied by Plans and explanatory Drawings, of any work in Civil Engineering, as far as absolutely executed, and which shall contain authentic details of the progress of the work. (Smeaton's Account of the Edystone Lighthouse may be taken as an example.)

"2ndly. Models, or Drawings, with descriptions of useful Engines and Machines; Plans of Harbours, Bridges, Roads, Rivers, Canals, Mines, &c.; Surveys and Sections of Districts of Country.

"3rdly. Practical Essays on subjects connected with Civil Engineering, such as Geology, Mineralogy, Chemistry, Physics, Mechanic Arts, Statistics, Agriculture, &c.; together with Models, Drawings, or Descriptions of any new and useful Apparatus, or Instruments applicable to the purposes of Engineering, or Surveying."

EXCERPT BYE-LAWS, SECTION XIV., CLAUSE 3.

"Every Paper, Map, Plan, Drawing, or Model presented to the Institution shall be considered the property thereof, unless there shall have been some previous arrangement to the contrary, and the Council may publish the same, in any way and at any time they may think proper. But should the Council refuse, or delay the publication of such Paper, beyond a reasonable time, the Author thereof shall have a right to copy the same, and to publish it as he may think fit, having previously given notice, in writing, to the Secretary of his intention. No person shall publish, or give his consent for the publication of any communication presented and belonging to the Institution, without the previous consent of the Council."

INSTRUCTIONS FOR PREPARING COMMUNICATIONS.

The Communications should be written in the impersonal pronoun, and be legibly transcribed on foolscap paper, about thirteen inches by eight inches, the lines being three-quarters of an inch apart, on the one side only, leaving a margin of one inch and a half in width on the left side, in order that the sheets may be bound.

The Drawings should be on mounted paper, and with as many details as may be necessary to illustrate the subject. Enlarged Diagrams, to such a scale that they may be clearly visible, when suspended on the walls of the Theatre of the Institution, at the time of reading the communication, should be sent for the illustration of any particular portions.

Papers which have been read at the Meetings of other Scientific Societies, or have been published in any form, cannot be read at a Meeting of the Institution, nor be admitted to competition for the Premiums.

ORIGINAL COMMUNICATIONS,

DRAWINGS, PRESENTS, &c.,

RECEIVED BETWEEN JUNE 30th, 1862, AND JUNE 19th, 1863.

ORIGINAL COMMUNICATIONS.

AUTHORS.

Austin, C. E. No. 1,077.—On Exploring and Setting Out Lines of Communication for Roads and Railways in Foreign Countries.

Brooks, W. A. No. 1,081.—Memoir on the River Tyne.

Brunton, J. No. 1,090.—Description of the Line and Works of the Scinde Railway. With Plans, Sections, Charts, and Drawings.

Clutterbuck, Rev. J. C. No. 1,074.—On the Perennial and Flood Waters of the Upper Thames. With a series of Diagrams.

Colburn, Z. No. 1,091.—On American Iron Bridges. With a series of Diagrams.

Fairbairn, W. No. 1,088.—On the Reconstruction of the Dinting and the Mottram Viaducts. With three Diagrams.

Fernie, J. No. 1,095.—On the Manufacture of Duplicate Machines and Engines. With a series of Diagrams.

Fraser, J. G. No. 1,075.—On the Construction of the Lydgate and of the Buckhorn Weston Railway Tunnels. With three Drawings.

Hawkshaw, J. No. 1,092.—Account of the Cofferdam, the Syphons, and other Works, constructed in consequence of the failure of the St. Germains' Sluice of the Middle Level Drainage. With a series of Drawings and Diagrams.

Hayter, H. No. 1,093.—The Charing Cross Bridge. With a series of Drawings and Diagrams.

Makinson, A. W. No. 1,076.—On some of the Internal Disturbing Forces of Locomotive Engines. With a series of Diagrams.

AUTHORS.

Miller, D. No. 1,082.—Structures in the Sea, without Cofferdams; with a Description of the Works of the New Albert Harbour at Greenock. With a series of Drawings.

Peniston, W. M. No. 1,089.—Public Works in Pernambuco, in the Empire of Brazil.

Preece, W. H. No. 1,079.—On Railway Telegraphs, and the Application of Electricity to the Signalling and Working of Trains. With a series of Diagrams.

Rostaing, Baron de. No. 1,086.—The Separation (Diffusion) of Metals, in a Liquid State, by means of Centrifugal Force.

Watson, W. No. 1,094.—On the Communication between London and Dublin.

CATALOGUE OF PRESENTS.

BOOKS.

DONORS. TITLE OF WORK.

Abernethy, J. Italian Irrigation Canal Company (Canal Cavour). With appendix and report by J. Abernethy. Tract. 8vo. London, 1862.

Académie Royale des Sciences, des Lettres, et des Beaux Arts de Belgique. Bulletin. Tomes XIII. and XIV. 2me serie. 8vo. Plates. Bruxelles, 1862.

——— Annuaire. 1863. 8vo. Plates. Bruxelles, 1863.

——— Mémoires Couronnés et autres Mémoires. Tomes XIII. and XIV. 8vo. Bruxelles, 1862.

——— Catalogue de la Bibliothèque de M. le Baron de Stassart, leguée à l'Académie Royale de Belgique. 8vo. Bruxelles, 1863.

Adair, Col. The Lines of London. Defences by Works and Manœuvre in the Field. Tract. 8vo. Map. No place or date.

[From the Journal of the Royal United Service Institution, Vol. VI.]

Airy, G. B. Report of the Astronomer Royal to the Board of Visitors of the Royal Observatory. Greenwich. Tract. 4to. London, 1863.

Akademie der Wissenschaften. Abhandlungen der Mathemat-Physikalischen Classe der Kön. Bayer. Neunter Band. 4to. Plates. München, 1863.

——— Sitzungsberichte. 1862, 1863. Band I. Heft 1, 2. 8vo. Plates. München, 1862—63.

Anonymous. Cursory Thoughts on some Natural Phenomena; bearing chiefly on the Primary Cause of the succession of New Species, and on the Unity of Force. Tract. 8vo. New York, 1862.

——— The Exchange. No. 4, July. 8vo. London, 1862.

——— Water for Domestic Use. By W. A. O'Doherty. Tract. 8vo. London, 1862.

——— Ericson's Monitor of 1854. America, not England its birth-place. Ericson, not Coles, inventor of the Revolving Cupola. Plate. New York, no date.

DONORS. TITLE OF WORK.

Architecten-und Ingenieur-Vereins für das König. Hannover. Zeitschrift. Band VIII. Heft 3, 4. 4to. Plates. Hannover, 1862.

Architectural Publication Society. The Dictionary of Architecture. Part XIII. The letter G. Gabi. to Granary. No. II. Year 1860. Folio. London, 1863.

Association for the Prevention of Steam Boiler Explosions, Manchester. Report of the Committee of Management, to be presented to the Subscribers at the eighth Annual General Meeting, to be held at the Town Hall, Manchester, on Tuesday, February 3rd, 1863. Tract. 8vo. Manchester, 1863.

Benson, Sir J. The Industrial Resources of Ireland. By Robert Kane. Second Edition. 8vo. Maps. Dublin, 1845.

Bormann, Major-General. The Shrapnel Shell in England and in Belgium, with some reflections on the use of this projectile in the late Crimean War. By Major-General Bormann. Second Edition. 8vo. Brussels, 1862.

——— Das Preussische System der gezogenen Feldgeschütze in Belgien und der Zeitzünder der Armstrong'schen Granat-kartätsche. Von Bormann. 8vo. Darmstadt & Leipzig, 1861.

Boston Public Library. Tenth Annual Report of the Trustees. 8vo. Boston, 1862.

Bourdon, E. Exposition Universelle de 1862 à Londres. Appareils imaginés et construits par M. E. Bourdon. Tract. 8vo. Plate. Nancy, 1862.

Boxer, Lieut.-Col. An answer to a pamphlet written by Col. Lefroy, R.A., F.R.S., in reply to the Author's remarks on the system proposed by the Royal Commissioners for the defence of the Country. By Lieut.-Col. E. M. Boxer, R.A., F.R.S. 8vo. Woolwich, 1862.

British Association for the Advancement of Science. Report of the Thirty-first Meeting held at Manchester in September, 1861. 8vo. Plates and cuts. London, 1862.

British Meteorological Society. Des Climats de la France, et de leur influence sur son agriculture et le génie de ses habitants. Par M. Ch. Martins. Tract. 8vo. No place or date.

[Extrait de l'Annuaire Météorologique de la France, 1850.]

——— Des Lignes Isothermes Mensuelles. Par M. H. W. Dowe. Traduite de l'Allemand par M. Ch. Martins. Tract. 8vo. Maps. No place or date.

[Extrait de l'Annuaire Météorologique de la France, 1850.]

——— Electrical Magazine. Conducted by C. V. Walker.

DONORS. TITLE OF WORK.

July 1843 to Oct. 1846. Two vols. 8vo. Cuts. London, 1843-46.

British Meteorological Society. Essai sur la nature et l'origine des différents espèces de Brouillards Secs. Par M. Ch. Martins. Tract. 8vo. No place. 1850.

[Extrait de l'Annuaire Météorologique de la France, 1850.]

——— Maritime Conference held at Brussels for devising an uniform system of Meteorological Observations at Sea. August and September, 1853. 4to. Plans. Bruxelles. No date.

——— Meteorological Journal for October, 1841. By W. H. B. Webster. Tract. 4to. London, 1841.

——— Meteorology in its connection with Agriculture. By Prof. J. Henry. Tract. 8vo. Plate and cuts. Washington, 1858.

[From the Agricultural Report of the United States Patent Office, 1856.]

——— Nautical Monographs. No. 1. By M. F. Maury, U. S. N. Tract. 4to. Plates. Washington, 1859.

——— Notice sur les altitudes du Mont-Blanc et du Mont-Rose, déterminées par des mesures Barométriques et Géodésiques. Par M. le Commandant Delcros. 8vo. No place or date.

[Extrait de l'Annuaire Météorologique de la France, 1851.]

——— On the present state of Meteorological Science in England. By J. Drew. Tract. 4to. Plate. London, 1850.

——— Séries Météorologiques correspondantes à celles du Faulhorn et du Mont-Blanc. 8vo. No place or date.

[Extrait de l'Annuaire Météorologique de la France, 1851.]

——— Séries Météorologiques faites au Sommet du Faulhorn, au Grand Plateau du Mont-Blanc, à Brienz et à Chamounix en 1840, 1842, et 1844. 8vo. No place or date.

[Extrait de l'Annuaire Météorologique de la France, 1850.]

——— Transactions of the Meteorological Society. Vol. I. 8vo. Plates and cuts. London, 1839.

——— 11th Report of the Council for the year 1861. 8vo. Plate. London, 1862.

——— U. S. Naval Astronomical Expedition to the Southern Hemisphere during the years 1849-1852. Vol. IV. Magnetical and Meteorological Observations, under the direction of Lieut. J. M. Gilliss, LL.D. 4to. Washington, 1856.

DONORS. TITLE OF WORK.

Britten, B. Rifled Ordnance. Remarks on the Report of the Ordnance Select Committee on Competitive Rifled Guns. Tract. 8vo. Plate. London, 1863.

Broise and Thieffry, M.M. Album Encyclopédique des Chemins de Fer. 10, 11, 12, 13, and 14 liv. Folio. Plates. Paris, 1862-63.

Burder, W. C. The Meteorology of Clifton, being the results of ten years' observations of the barometer, rain, &c. By W. C. Burder. 8vo. Clifton, 1863.

Buresch, E. Mittheilungen des Sæchsischen Ingenieur-Vereines. Herausgegeben von dem Verwaltungs-rathe des Vereines. Drittes Heft. 8vo. Plates. Dresden, 1860.

———— Pläne der neuen Irrenanstalten zu Göttingen und Osnabrück. Von Baurath Funk und Bau-Conducteur Rasch. 4to. Plates and Cuts. Hannover, 1862.

Burnell, G. R. The Annual Retrospect of Engineering and Architecture; a record of progress in the sciences of Civil, Military, and Naval Construction. Edited by G. R. Burnell. Vol. I. January to December, 1861. 8vo. Cut. London, 1862.

Buzzi, Sig. Verbindungs—Kanal der beiden Buchten von Triest und Muggia mit Berücksichtizung des Schiffsbaues und der Industrie, sowie einer eventuellen Bahn nach Istrien, resh. Pola. Zur Triester Hafenfrage. Von H. Rieter. 8vo. Plates. Triest, 1862.

Canadian Institute. The Canadian Journal of Industry, Science, and Art. New Series. Nos. 39, 40, 41, 42, 43, and 44. 8vo. Cuts. Toronto, 1862-63.

Catholic University of Ireland. The Atlantis: or Register of Literature and Science of the Catholic University of Ireland. Nos. VII. and VIII. 8vo. Plates. London, 1863.

Cavalli, J. Mémoire sur la Théorie de la Résistance Statique et Dynamique des Solides, surtout aux impulsions comme celles du Tir des Canons. Par Jean Cavalli. Tract. 4to. Plates Turin, 1863.

Cerero, R. Memoria sobre las armaduras destinadas a sostener las cubiertas de los edificios, Por el Capitan del Cuerpo de Ingenieros Don Rafael Cerero. Tract. 8vo. Plan. Madrid, 1863.

Chadwick, E. On the Manual Labourer as an investment of Capital. By E. Chadwick. Tract. 8vo. London, 1862.

Chemical Society. Journal. Vol. XV. Aug. to Dec., 1862.

DONORS. TITLE OF WORK.

Vol. I. New Series. Jan. to June, 1863. 8vo. Plates. London, 1862-63.

Clyde Trustees. Reports on the Improvement and Management of the River Clyde and Harbour of Glasgow, from 1755 to 1862. 8vo. Glasgow, 1854-62.

Coignet, F., through J. W. Papworth. Bétons agglomérés appliqués à l'art de Construire, notamments à l'état monolithe et à l'état de pierres artificielles. Par François Coignet. 8vo. Paris, 1861.

Colthurst, J. Dwellings for the Poor. A Letter to the Rt. Hon. Lord Stanley, M.P., by Joseph Colthurst. Tract. 8vo. London, 1863.

Cutler, W. H. Holmes's Magneto-Electric Light as applicable to Lighthouses. 8vo. Plate. London. No date.

Daly, C. Revue Générale de l'Architecture. Par C. Daly. Vol. XX. Nos. 5, 6, 7, 8, 9, and 10. Vol. XXI. Nos. 1, 2, 3, and 4. 4to. Plates and Cuts. Paris, 1863.

Danvers, J. Report to the Secretary of State for India in Council on Railways in India, for the year 1861-62. By Juland Danvers. Folio. Plates. London, 1862.

Delesse, M. Carte agronomique des environs de Paris, 1862.

[Extrait du Bulletin des Séances de la Société Impériale et Centrale d'Agriculture de France. Année, 1862.]

———— Recherches sur l'eau dans l'intérieur de la terre. Tract. 8vo. Paris. No date.

[Extrait du Bulletin de la Société Géologique de France, 2e série, t. XIX., p. 64. Séance du 4 Novembre, 1861.]

———— Exposition Universelle de 1862. Matériaux de Construction. Par M. Delesse. 8vo. Paris, 1863.

Denton, J. B. Remarks on the Land Drainage Act, 1861. In three letters, reprinted from the "Agricultural Gazette." By J. B. Denton. Tract. 4to. London. No date.

Department of Public Works, Melbourne, through W. W. Wardell. Mining Surveyors' Reports. Jan., April, July, 1862, Jan., 1863. Tracts. 8vo. Melbourne, 1862-63.

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January 12, 1864.

JOHN ROBINSON M'CLEAN, President, in the Chair.

THE following Candidates were balloted and duly elected:—ROBERT CHAPMAN, TRAVERS HARTLEY FALKINER, and HENRY VOSS, as Members; CHARLES CHAMBERS, GEORGE HENRY COBB, HENRY BURDETT HEDERSTEDT, EBENEZER WILLIAM HUGHES, JAMES CARRINGTON SIMPSON, and THOMAS HITCHIN SMITH, as Associates.

Mr. M'CLEAN addressed the Meeting in the following terms, on taking the Chair for the first time, after his election as President:—

GENTLEMEN,

The greatest honour a Civil Engineer can attain is to become the President of this Institution, and I beg to thank you for having, by your suffrages, placed me in that distinguished position.

I feel deeply the responsibility of presiding over an Institution, comprising, as it does, upwards of one thousand Members and Associates, gentlemen who personally represent every branch of Civil and Mechanical Engineering and practical science, and amongst whom there are so many better qualified than I am to occupy this Chair. But as you have not considered it necessary to depart from the custom of electing your senior Vice-President to the important office of President, I will accept the trust, and endeavour, with your continued support, to discharge conscientiously the duties connected with that office.

My first duty is to address you on assuming the Chair, and I will now claim your attention to the few general remarks I have to make.

The progress of Engineering science has been so fully recorded by my distinguished predecessors in office, that I propose on the present occasion, instead of describing any Engineering works, to point out the extraordinary effects these works have exercised, during the last thirty years, in promoting the material and intellectual progress of Great Britain, and increasing the comforts and

social enjoyments of all classes of its inhabitants. I will endeavour to show that the wonderful prosperity attained during that period is to be attributed mainly to our Railway system, which has enabled us to develop the mineral resources of the country, and at the same time to provide secure and reproductive investments for the profits realised by the successful working of the system.

It is a prevalent opinion, that the increased prosperity of the country, to which I refer, has been the result of improvements in the cultivation of the land, better drainage and farming, and in consequence of the railway system having provided better means of access to markets and places for disposing of the products of the soil, and obtaining suitable materials for renewing its fertility. In order to show the incorrectness of this opinion it will be necessary to refer to the Reports of the Commissioners of Inland Revenue, which give returns of the property and income of Great Britain, at two different periods especially suitable for the comparison I wish to make; one before the works of the Civil Engineer had attained much importance, and the other after the successful application of the Steam Engine to Locomotive purposes had led to the construction of our present magnificent system of Railways.

The years selected for the purpose are 1815, and 1856, the return of the property and income of the country being fully given for those years in the Reports of the Commissioners. Besides, the year 1815 was the last year of the income tax in which accurate statistics can be obtained of the property and income of Great Britain. It was also the last of a long series of years of war, during the whole of which the property and income tax had been in operation; and, as the financial necessities of the Government were great, we may safely accept these returns as accurate, and rely that no source of income, or property, which could be brought within the operation of the Chancellor of the Exchequer, has been omitted from the account, and allowed to escape taxation. It was, moreover, a period in which most of the great discoveries of the Engineer, except the Locomotive Engine, were in full operation. The steam-engine as improved by Watt, had been in operation forty years before, pumping water from mines, raising minerals, and providing motive power; and Arkwright and other great inventors had perfected the machines employed in textile manufactures, and had brought them into general use.

In the Returns referred to we find each source of income under a separate head; and, in order to make the comparison as simple as possible, I take in all cases the amount of the tax under that head as the measure of the value of the property or income assessed, as set forth in the following Table:—

TABLES

OF THE NET AMOUNT OF THE PROPERTY AND INCOME OF GREAT BRITAIN, FROM ALL SOURCES, LIABLE TO ASSESSMENT FOR TAXATION IN THE YEARS 1815 AND 1856.

TABLE No. 1.

YEAR 1815.

LAND :—	£.
Land, Tithes, Manors, Fines	£41,521,492
HOUSES (exclusive of Farmers' houses)	16,259,400
PROFITS ON REALIZED PROPERTY :—	
Quarries, Mines, Ironworks, &c.	1,452,104
Farmers' profits . . .	21,762,280
Funds	30,048,620
Profits of Trade and Professions	30,211,880
Government Departments	11,132,450
Total . .	£152,388,226

Incomes and Profits exempt under £50 per annum during this year.

TABLE No. 2.

YEAR 1856.

LAND :—	£.
Land, Tithes, Manors, Fines, Fisheries	£38,153,935
HOUSES (exclusive of Farmers' houses)	48,435,585
PROFITS ON REALIZED PROPERTY :—	
Quarries, Mines, Ironworks, Canals, Railways, Gas Works, And other Property	18,087,963
Farmers' profits . . .	24,224,443
Funds	24,407,360
Profits of Trade and Professions	74,551,046
Government Departments	14,607,036
Total . .	£242,467,368

Incomes and Profits exempt under £100 per annum during this year.

In Table No. 1 we find, that in the year 1815, or forty years after the steam-engine had been improved and used for saving labour and producing motive power in connection with mining and manufactures, the whole annual income derived from quarries, mines, ironworks, and other property was only £1,452,104.

In Tables No. 1 and 2 we find the net income available for taxation, derived from land, and the profits of the farmers, taken together, in 1815 to be £63,283,772; whilst in 1856 it was only £62,378,378.

The net income derived from houses during the same period, had increased from £16,259,400, to £48,435,585, an augmentation of £32,176,185, or nearly three hundred per cent.

The net profits derived from mines, quarries, ironworks, canals, railways, and other profits, had increased from £1,452,104 in 1815, to no less a sum than £18,087,963 in 1856, or upwards of twelve hundred per cent.

From these figures we learn that during the forty years, over which the comparison extends, the profits and income of land together had not increased, notwithstanding the construction of roads, railways, canals, and other public works, and the relief from poor-rates afforded to it by the extension of the rate on other property, and by the absorption of the increased population in new occupations (as shown by the Population Returns), the number of labourers employed on the land at the Census of 1861 being less than in the year 1815. No doubt the condition of all classes connected with the land, including the landlord, farmer, and agricultural labourer, had improved during the period in question, and much capital had been expended in farm-buildings, drainage, and machinery. Yet the net annual income available for taxation in 1856, derived from land and farmers' profits, was not greater in 1856 than in 1815, although the income derived from all other sources of property, during the same period, had largely increased, as we find in the Tables,—the net amount of income derived from the profits of trades and professions available in 1815 being £30,211,880, and in 1856, £74,551,046, showing an increase in the latter year of nearly 150 per cent., the exemptions from Income Tax being under £50 per annum in 1815, and under £100 in 1856.

In these Tables we also find the total net amount of income derived from all sources available for taxation in 1815, to be £152,388,226, and in 1856, £242,467,368, showing an increase of sixty per cent., or upwards of £90,000,000 (which, on the basis of the taxation of 1815, would have yielded £9,000,000 additional tax), from sources independent of the land.

I will now attempt to point out the causes of the enormous increase of the income of Great Britain, shown by the Tables, representing the profits of many hundreds of millions sterling in-

vested in railways, canals, mines, ships, and other works, in this country, in India, and in our colonies.

Fortunately the railway system, since the introduction of the locomotive engine, improved by Stephenson, gave it vitality, has been a complete success, in the reproduction of capital, in the enormous saving in the cost of transport, and in the facilities it affords for the development of mines, and of nearly all branches of national industry.

After the opening of the Manchester and Liverpool Railway, the accumulated wealth of Great Britain, which, previous to that time had been but sparingly invested in public undertakings, and was for the most part hoarded, or placed on doubtful securities, was thrown lavishly into the railway system; and, although for a time this led to the belief, that the supply of capital for the construction of such undertakings was inexhaustible, and induced excess of speculation, temporary distress, and subsequent distrust in the system; yet the progress of railways ever since that period has been steady, and a reproductive profit has been assured on a capital of nearly £400,000,000. This vast capital has been created because railway securities, on the principle of limited liability, occupy the highest place in public estimation, for investing the realised profits of the country, in consequence of the facility with which they can be purchased, and transferred in amounts suited to the requirements of every class of society; and this leads to a constant accumulation of capital by inducing people to save a portion of their income,—not merely for their own support in an after-period of life, but for the benefit of their descendants. Thus railway securities afford the means of transmitting wealth, as printing does knowledge, from one generation to another.

The beneficial effects of the railway system has not been confined to Great Britain. Before the introduction of railways the land was nearly the only safe means in Europe for the investment of capital; and, in consequence of the competition for this security, the interest was reduced to a minimum rate, and was barely sufficient to induce people to save a portion of their income. The construction of railways, by inducing saving, has established a wealthy and educated middle class in most countries in Europe, who have not only developed the industrial resources and increased the capital of the country to which they belong, but have also, as in this country, promoted education, and humanized the conduct of all classes of the people.

I have only one more remark to make on railways as a cause of the increase of wealth. The land occupied by railways in Great Britain is under two hundred thousand acres, including stations and other conveniences, and to obtain possession of this land it has been

necessary, during every session of Parliament, for the last thirty years, to engage the services of the ablest Counsel and the most eminent Engineers in the Committee Rooms of both Houses at an incalculable expense. The land used for agricultural purposes is about forty million acres, and yet the railway system, occupying only about one half per cent. of the total area of the land, now pays nearly as great an amount of Income and Property Tax as is paid by the whole of the farmers of Great Britain.

Another source of wealth is the great deposit of coal, and iron, stone, and other minerals—in nearly every part of the kingdom.

The most important of these is coal. The quantity of coal raised in Great Britain is now about one hundred millions of tons yearly, produced by the labour of about three hundred thousand men.

We are indebted to Professor Liebig, the celebrated German chemist, for data by which we can estimate the value of this enormous quantity of fuel, by comparing it with wood, or any other produce of the soil.

Liebig informs us, that every acre of fertile land will produce yearly about two tons and a half of wood, or other crop, which contains about the same quantity of carbon (80 per cent.) as one ton of coal. The one hundred million tons of coal now raised annually from our mines contain about eighty million tons of carbon: and to produce the equivalent of this in wood would require one year's growth of, in round numbers, one hundred millions of acres of land,—an area about four times larger than the arable and pasture land of England, (which does not exceed twenty-five million acres,) and as nearly as possible equal in extent to the area of the empire of France. Yet this supply of fuel, even if it existed in the form of wood, would be practically useless as a substitute for coal; the labouring population of the kingdom would be unable to cut and convert it, the whole of our railways and canals would not suffice to transport it, while the cost of these operations, if no other obstacle intervened, would prevent them from being carried on beneficially.

The development of coal, then, is mainly the cause of the increase of wealth, but if railways had not proved reproductive investments, this mineral would have added little more to the wealth of Great Britain than it did in 1815, as shown by Table No. 1.

The serious question as to the permanence of this fuel, on which the wealth of the nation so much depends, has been prominently raised. Since the great discovery of Murchison that coal underlies, and may be found with reasonable certainty under the lower new Red Sandstone and Permian formations, which extend over millions of acres of Great Britain; and, if beneath them, at greater depths, under all the measures which overlie the Permian, and which, together, comprise upwards of one half the area of Great

Britain, we may consider our coal-mines to be practically inexhaustible, and that we have not to fear any deficiency in quantity, arising from the exhaustion of the mineral, but rather the practical difficulty of obtaining it from a great depth below the surface, in consequence of the Central Heat of our Globe, which, it is alleged, will ultimately, and within a defined and not distant period, reduce the production to a limited supply.

Much may be said in support of the Theory of Central Heat, but I think undue importance has been given to it, as a difficulty in mining operations. A comparatively thin coating of clay, or fire-bricks, surrounding a blast furnace filled with molten iron, affords such protection that the hand may be placed without inconvenience on the outer surface of the brick-work, and it is difficult to understand how any internal heat can penetrate through the crust of the earth,—estimated to be thirty-four miles in thickness,—so as to interfere with the temperature at the comparatively small depth from the surface at which mining operations are carried on. I am of opinion that the heat, which undoubtedly exists in some mines, arises, not from central heat, but from superincumbent pressure, and defective ventilation. The gases in the coal are highly compressed, and, when liberated by mining operations, are at a high temperature; but we know that with large shafts air may be conveyed to any depth that has yet been reached in mining operations, without in the slightest degree altering its temperature; and that by a proper enlargement of the air passages, air descending the shaft may be distributed through the workings, so as to lessen the liability of accident from explosion, or serious inconvenience from heat, at any depth to which shafts can be sunk. The system of sending compressed air down the shaft by means of water is found to abate inconvenience in deep mines owing to an excess of temperature.

I therefore think that the time when we shall experience a want of coal, arising from exhaustion, or from difficulties occasioned by the depth of the mines, or an excess of temperature, need not at present in any way influence our conduct in the development and use of that important mineral; especially as the power (which is the substitute for labour) derived from coal is so cheap, that we are enabled to consume daily for our domestic comforts, for machinery in the conversion of minerals, and for other manufacturing processes, and for export, a power equal to twelve millions of horses, at a cost, at the mine, of not more than one penny per horse-power, working ten hours a day, and no saving in consumption of this enormous quantity of coal can be made, except by employing more expensive labour as a substitute.

With this power at our command the cost of sinking to, and of

raising minerals from the greatest depths, is inappreciable; while the intrinsic value of coal, when compared with any other fuel, is so great that it may be drawn profitably from almost any depth,—the only limit being the strength of the machinery and materials required to raise it.

The next mineral in importance is ironstone.

In the year 1862 the production of ironstone and iron ore in the United Kingdom amounted to 7,586,956 tons, which, by the operation of five hundred and sixty-two blast furnaces, was converted into 3,943,469 tons of pig iron.

The importance of the iron and coal trade as a source of wealth is proved by the fact, that the declared value of the iron and coal exported from this country during 1862, either in a raw, or a manufactured, or a partially manufactured state, was nearly £25,000,000, due altogether to the development of our natural resources; and this sum represents the cost price only, and is exclusive of carriage, or freight and profits of trade, which may fairly be taken to represent one half more.

In 1862 our other mines produced the following quantities of minerals, viz.:—

Tin ore	14,127 tons.
Copper ore	224,171 „
Lead ore	95,311 „
Zinc (blende)	7,497 „
Pyrites (sulphur)	98,433 „
Salt	981,598 „
Fire-clay, china-clay, and porcelain stone	853,803 „

These minerals, and the metals produced from them by means of coal, have enabled us, with the assistance of the shipping interest, to obviate, to a great extent, the effects of the failure in the supply of cotton; for notwithstanding the great decrease of the export of cotton goods (to the extent of £10,000,000 in the year 1862), the total amount of exports during the financial year just ended (1863) has been £124,137,812, exclusive of carriage and freight, and we have thus been enabled to pay for all imports, and partially to alleviate the distress among the cotton operatives in Lancashire.

I will not occupy your time in detailing all the various profitable employments which result from mining and manufacturing operations, but will only refer to, perhaps, the most remarkable of them—ship-building.

The Government returns for 1861 show, that in that year 975 ships, representing 200,839 tons, were built and registered in the United Kingdom;—of these 91,095 tons were constructed of iron,

the average of the iron vessels being a burthen of 430 tons each.

And this, it should be remembered, is exclusive of iron ships built in private yards for the Royal Navy, and of the ships constructed for foreigners.

The iron screw steam-ships, in consequence of their great and regular speed, due to engineering skill, have practically become an extension of the railway system, over all parts of the world, and have enabled us more freely to exchange the products of our industry for those of other nations, thereby conducing to the employment, the intellectual and social enjoyment, and the convenience of the people, and providing for the further increase of population and universal wealth.

On these considerations I am justified in stating, that the increase of the income of England since the year 1815, has not arisen from the land; but that it is mainly due to the discoveries of our great engineers. There remains still to be considered the question of the distribution of this wealth, which has been the means of providing profitable employment for millions of a rapidly increasing population who, but for such industrial undertakings must have remained a burthen on the land, and a cause of poverty and discontent; unless reduced in number by famine, or by extensive emigration.

The Tables I have given show that the wealth has been fairly distributed among all classes of society, and that while the "rich have been growing richer, the poor have become less poor;" and that the "wide interval that formerly separated the extremes of wealth and poverty" is being gradually closed, not by the reduction of wealth, but by the diminution of poverty, arising mainly from the mining and industrial sources which I have described.

We may also congratulate ourselves that this wealth has not been employed in reproductive undertakings alone, but that the great cause of education has felt the stimulus of it, and that every year the importance of developing and directing the intelligence of the people is more distinctly recognized.

I will now make a few remarks on the extension of the railway system, and especially on the construction of the proposed new lines in the metropolitan districts. It is evident that parliamentary sanction will not be given to all the lines which have been suggested, but the convenience of the public, and the necessity for relieving the streets from the heavy traffic passing to and from the present railway stations, require that some of these lines should be constructed without delay. The success of Mr. Fowler's Metropolitan Line, due to the talent exhibited in its construction, as well as to the tenacity of its promoters in overcoming all difficulties,—those of finance not being the least,—has proved that

Railways in the metropolis can be made a source of profitable investment.

Much has been said as to the destruction of property which, it is assumed, will result from the execution of the proposed metropolitan extensions, and the question has been discussed, as if the property taken were wasted, or destroyed, forgetting that it is only a change of occupation, and that the houses pulled down will, in many cases, be much better restored, in accordance with modern sanitary improvements, or the sites will be applied to more profitable uses, tending to the general improvement of the metropolis, the convenience of the public, the relief from local taxation, and the better occupation of the working-classes.

The construction of these railways, by means of private funds, is less objectionable than by funds derived from a tax on the coal and wine dues, or any other mode of local, or public taxation. If public funds were to be resorted to, the works now so much needed would never be executed, as the enormous capital required would prevent either local boards, or the Government itself from undertaking them. Besides, it is only right that those who use these railways should pay for them, and not people living remote from the metropolis who may never enjoy them.

Occasionally unproductive works of national importance, such as the Thames Embankment, may be executed at the public expense, but the principle of Government construction is inadmissible in this country, in the case of railways or any other public work which can be rendered reproductive by private enterprise.

In consequence of the great interest now evinced in the progress of the works of the Isthmus of Suez Canal, and as the subject has never been brought directly under the consideration of the Institution, I will take this opportunity to make a short statement respecting the labours of the English members of the International Commission, who in the years 1855 and 1856, examined the question of the practicability of forming a ship canal through the Isthmus of Suez.

In the year 1855 M. Ferdinand de Lesseps, acting for H.H. the late Said Pacha, Viceroy of Egypt, invited me with the late Mr. Rendel, and your Honorary Secretary, Mr. Manby, to form part of an international commission, for the purpose of considering and reporting on the practicability of forming a ship canal between the Mediterranean and the Red Sea, and the best mode of constructing it, and for that purpose I accompanied M. Conrad, of Holland, MM. Rénaud and Liéussou of France, and M. de Négrelli of Vienna, to Egypt in that year. The commission was an honorary one, and we were considered the guests of the Viceroy from the time of our leaving Marseilles to our return to Europe.

In Egypt we met M. de Lesseps, Mougel Bey, and Linant Bey,

Engineers, and other gentlemen in the service of the Viceroy, and in the months of December 1855 and January 1856, we made a careful examination of the harbours in the two seas, which it was proposed to unite, and of the desert lying between them, and arrived at the conclusion, that a ship canal was practicable between the Gulf of Pelusium in the Mediterranean and the Red Sea, near Suez. Thus far we all agreed, but we differed as to the mode of construction. The English members were of opinion that a ship canal raised twenty-five feet above the sea-level and communicating with the Bay of Pelusium at one end, and the Red Sea at the other, by means of locks, similar to the sea-entrances of the Caledonian Canal, might be constructed, there being no difficulty in abundantly supplying the canal, at all times, with water from the Nile, by a cut made from a suitable level, without depending in any way on the closing of the 'Barrage' of the Nile. The foreign members of the Commission were, however, of opinion, that a canal twenty-seven feet below the sea-level from sea to sea, without any lock, was the best system, with harbours at each end, one to be constructed in the Mediterranean by piers and dredging, and the other in the Red Sea by dredging to the deep water, which in both seas is at a considerable distance from the shore.

On a comparison of the two systems it was found that the ship canal above the sea-level, with locks, would save many millions of cubic yards of excavation, principally dredging, a difficult and expensive operation, and would involve no more than the ordinary contingencies which might attach to any similar engineering work of equal extent, while the difficulty arising from rocks at Suez, and running sands and silt at Pelusium would be avoided, and a large sum of money saved in the cost of construction, by employing locomotive engines instead of human labour.

The English members also considered this system the best for the shareholders, and most calculated to give productive returns for the capital invested.

The whole of the members of the Commission [see Appendix, page 167], with the exception of Mr. Rendel, met at Paris in June 1856, when the Report of the English Engineers, signed by Mr. Manby on their behalf [see Appendix, page 164] was presented, and after full discussion, was rejected by the foreign members of the Commission, who preferred a canal without locks; and, as they formed the majority, the Report to H.H. the Viceroy recommended the system now actually in course of construction.

As the English Engineers were members of a purely honorary Commission, their labours terminated with the Report.

Five years after the discussion in Paris of the mode of construction by the International Commission, your Past-President, Mr. Hawkshaw, was requested by H.H. the late Viceroy to "exa-

mine the site of the proposed ship canal, intended to connect the Red Sea and the Mediterranean, across the Isthmus of Suez, and to report his opinion of that work." In February, 1863, he made a very able and elaborate Report, which details the actual progress of the ship canal and its accessories, up to the end of the year 1862, constructed in accordance with the system adopted by the majority of the Commission, from which it appears that there had been executed of the Ship Canal (principally dry earthwork) six million cubic metres out of ninety-six millions, or one-fifteenth part of the whole—the expenditure up to that period, including the partial execution of the fresh-water canal, being £1,200,000—leaving to be excavated ninety millions of cubic metres; or twenty millions of cubic metres more than the entire quantity required to complete the Canal according to the system proposed by the English Members of the Commission.

I will now address a few remarks to the Junior Members as regards the future prospects of the profession.

I have shown that, during the last thirty years, the works of the Engineer, or those executed under his direction, have led to the present prosperous condition of Great Britain—and by the extent of the works that have been done during that time we may fairly measure those that are yet to follow. The extension of the railway system is necessary for the progress and well-being of the world, and must be carried out by our young Engineers in this country and in every part of Europe, in India, and in our Colonies. There is no country that will not become richer by the introduction of railways, and the richer a foreign country becomes, the more it adds (by the extension of commerce) to the wealth and prosperity of this kingdom. And, if our railway system is extended, new harbours, docks, canals, steam ships and other Engineering works will be necessary to meet the requirements of traffic and the demands of increasing commerce.

Nothing but unwise legislation, and the imposition of restrictions on commerce, for which happily the public mind is not prepared, can prevent the progress of those great works—unless the railway system became a 'protected interest,' which would be disastrous to all mining and manufacturing undertakings, which mainly depend for their prosperity on the further development of the system; and also to the public, who would be deprived of their safest and best security for the investment of their annual savings. If Railway Companies were relieved from the risk of competition, instead of making new lines to meet the requirements of trade, and the wants of an increasing population, they would probably, with the view of improving the value of their shares, consider their best interest lay in imposing higher charges, and giving only limited accommodation to the public.

In conclusion, I hope the day will arrive when the basis of fixed taxation will be so extended as to enable the Government to abolish all our present Customs duties, nearly the last restrictions on commerce, which limit the free exchange of traffic between ourselves and other nations, and when free intercourse will be permitted to be carried on by railways and steam-ships, as part of one system, without interruption at the sea ports, and without the impediments and waste of labour and expense occasioned by the interference of bonding warehouses and Government officials, required under our present system of taxation.

APPENDIX.

ISTHMUS OF SUEZ CANAL.

Comparative advantages of the Two Systems, proposed for constructing a direct Canal between the Mediterranean and Red Seas.

FIRST SYSTEM.	SECOND SYSTEM.
(*Adopted by the* majority *of the Commissioners.*)	(*Proposed by the English Members of the Commission.*)
The level of the top water of Canal to be the same as the level of the low water of the Mediterranean Sea at Said.	The level of the top water of the Canal to be 7 metres above the low water of the Mediterranean Sea.

In each case the Canal to be 8 metres deep, and to have the internal slopes in cuttings 2 to 1, and in embankments 3 to 1. The width of the bottom in all cases to be 68 metres.

LOW LEVEL.	HIGH LEVEL.
The total quantity of excavation will be 130,000,000 cubic metres. One-half of that quantity below the natural drainage of the country, will require to be dredged.	The total quantity of embankment will not exceed 70,000,000 cubic metres, and may be much reduced by a judicious selection of the line of Canal.
The method proposed of forming a small Canal first, and afterwards enlarging it, is impossible, unless Lake Timsah and the Bitter Lakes are avoided. The stone found in the cutting cannot be made available for the harbour of Said, until the Canal is opened throughout.	The whole of the excavation will be above the natural drainage of the country, and may be conveyed with great rapidity into embankments, by means of railways and locomotive engines.
The difficulties arising from stone and running sand, forming part of the material, may be great; the former at Suez, the latter in Lake Menzaleh.	The stone found in the cuttings and in the ground adjoining El Guisr, may be used for the harbour of Said.
	The difficulties will not be greater than in an ordinary engineering work.
HARBOUR OF SUEZ.	HARBOUR OF SUEZ.
There will be considerable difficulty in forming a channel 400 metres wide and 3,000 metres in length, by dredging-engines, and every probability of meeting with coral reefs and indurated sands, or conglomerate, similar to the rocks at Suez.	The Canal may be carried round the Bay of Suez, in the manner shown upon the chart, and the locks formed in deep water, which will avoid the necessity of dredging, and all the risk attendant upon it.
	There will not be any necessity for jetties, as the harbour is completely sheltered, except from the north wind, and the embankment of the canal will afford ample protection.
	The Canal will be close to the quarries of Attaka, an object of great importance in the execution of the works of the Canal and harbours.

PORT TIMSAH.

The cost of establishing a port in Lake Timsah will be considerable, and much dredging will be required.

IRRIGATION.

A Canal is proposed between the Nile Branch Canal and Suez, for the purposes of irrigation and fresh water supply, and a conduit from the same branch to the Mediterranean, for similar purposes. Steam-engines of 500 horse-power, at a working cost of £27,000 per annum, are to be erected.

SUPPLY OF WATER.

The Canal will depend for a supply of water on tides of the Red Sea.

Unless there is a current out of the Bitter Lakes, as well as into them, the evaporation of 5,000,000 cubic metres of salt water daily, during three months in the year, will form deposits; as nearly 3 per cent. of salt will be deposited after a certain time, or 150,000 cubic metres daily.*

At the present time the water is salter at Suez than in the Pacific, and were it not for the constant outgoing current of brine at Babelmandel, the Red Sea would fill up with salt.

The tidal observations do not give the simultaneous condition of the tides at Suez and in the Mediterranean, nor the variation during each half-hour of low and ebb, so that it is impossible to estimate the velocity of the currents through the proposed Canal.

One great difficulty will be to fill the Bitter Lakes.

If the sea is freely admitted, the velocity into the lakes, even at low water, will be 6 feet per second, which would completely destroy the channel.

Even supposing them to be filled, the tides will barely be sufficient to supply the waste arising from evaporation and absorption, and a current will flow from both seas, until the channel gradually becomes filled up.

PORT TIMSAH.

The high level will save the cost of the locks at this point. The Maritime Canal and the Branch Canal to the Nile will be on the same level, and great expense will be avoided in the construction of wharves and other works.

Between the Nile and the Maritime Canal only two, or three regulating locks will be required.

IRRIGATION.

The Canal and conduit may both be avoided by adopting a higher level, and supplying the Canal from the Nile below the barrage. Irrigation may be carried on much more advantageously for the whole distance between Suez and the Mediterranean Sea, by supplying the Maritime Canal with fresh water, and using it as a great reservoir, during the inundations of the Nile (which would be impossible in a conduit).

The whole of Lake Menzaleh may be reclaimed.

SUPPLY OF WATER.

The supply of water will be direct from the Nile at its lowest level, and be regulated by locks during inundations.

There will not be any possibility of failure, either from winds or from scarcity, during dry seasons; the minimum discharge of the Nile being 50,000,000 cubic metres per hour.

The abstraction of 1-24th part of the water of the Nile during low-water time, and 1-30th part during inundation, will provide for loss of water, by evaporation and leakage, and for an average lockage of 100 vessels daily.

The deposit of the limon of the Nile will take place in the Branch Canal, and may be removed annually, without interfering with the navigation; or it may be sent down the Maritime Canal to sea, by scouring, in a particular method devised for that purpose.

* *Vide* Maury, "Physical Geography;" and Lyell, "Elementary Geology," p. 347.

HARBOUR OF SAID.

Two jetties, one 3,000 metres, and the other 2,500 metres, in length, will have to be constructed, and the space, 400 metres between, dredged and conveyed away in barges.

The stone must be brought from the islands in the Mediterranean Sea.

No dredging can take place until a temporary harbour has been constructed, as it is a lee-shore during nine months of the year.

There will be no back-water to keep the channel open; on the contrary, there will be a gradual flow into the Canal, which will tend to form a new beach in the Harbour and Canal.

There will be no certainty that the work will ever be finished. It will altogether depend on contingencies, over which the Engineer has no control, and which cannot be estimated.

HARBOUR OF SAID.

The locks and harbour may be constructed without more than ordinary difficulties, and no dredging will be required except at the tail of the lowest lock.

The stone from El Guisr may be used in the harbour, as a railway will be required for constructing the banks.

The scouring power of the water will always keep the channel open.

The contingencies will not be greater than usually belong to works of this magnitude.

Therefore, under the First System, the construction may be regarded as impracticable, whilst under the Second System it may be considered feasible.

Approved by

J. M. RENDEL and J. R. McCLEAN,

And signed by

CHARLES MANBY,

For the Members of the English Commission.

The International Commission was composed of the following Members, viz. :—

M. F. W. CONRAD	Chief Engineer of the Water-Staat, the Hague.
CAPTAIN HARRIS	Of the Honorable East India Company's Navy, London.
CAPTAIN JAURÈS	Of the Imperial Marine, and Member of the Council of the Admiralty, France.
M. LENTZE	Chief Engineer of the Works on the Vistula, Berlin.
M. LIÉUSSOU	Hydrographical Engineer to the Imperial Marine of France, Paris.
MR. J. R. McCLEAN . . .	Civil Engineer, London.
MR. CHARLES MANBY . .	Civil Engineer, London.
M. MONTESINO	Director of Public Works, Madrid.
M. DE NÉGRELLI . . .	Inspector-General of Railways in the Austrian Empire, Vienna.
M. PALÉOCAPA	Minister of Public Works in the Kingdom of Sardinia, Turin.
M. RÉNAUD	Inspector-General and Member of the Council for *Ponts et Chaussées*, Paris.
MR. J. M. RENDEL . . .	Civil Engineer, London.
M. RIGAULT DE GENOUILLY .	Rear-Admiral of the Imperial Marine of France, Paris.

No. 1,096.—"On the Closing of Reclamation Banks."[1] By John Mortimer Heppel, M. Inst. C.E.

Reclamation works, of great magnitude, having been proposed upon the Essex coast, and various opinions having been expressed as to the extent to which the difficulty of closing the banks would be influenced by the area to be reclaimed, a Member of the Institution, to whom those works were to be intrusted, requested the Author to investigate the subject, and to reduce his views to a precise statement; and although the inquiry instituted had reference to a particular case, it is hoped that the method then adopted may possess some general interest, as being applicable to all similar undertakings.

The site of the proposed operations was the long foreshore, lying between high and low water levels, between the mouths of the Blackwater and Crouch rivers, constituting St. Peter's Sands, Dengie Flats, and the Ray Sands. The extent to be reclaimed was about 7,000 acres, and the length of sea wall to be constructed about 10 miles. Similar operations, to a still larger extent, were contemplated on the Maplin Sands, lying between the Crouch river and the mouth of the Thames. The average rise of the tides in these places was taken for springs at 15 feet, and for neaps at 11 feet.

It was considered desirable, with a view to facilitate the ultimate closing of the reclamation banks, that the closing places should be constructed in the first instance of timber, and other suitable materials, in a solid and substantial manner, so as to be capable of resisting any amount of scour to which they might become exposed; and the main point of inquiry was, the width it would be necessary to give to these places, which would at last become the only communication open between the interior and the exterior water.

This width, it was considered, ought to be sufficient to drain out all the interior water at every tide; so that by closing the openings at low water, the tide might be permanently excluded. At the same time, it is obvious that any great excess above what is requisite for this object would add, unnecessarily, to the difficulty of closing. To ascertain this width in any given case, it is necessary to investigate the whole action which takes place consequent

[1] The discussion upon this Paper occupied portions of two evenings, but an abstract of the whole is given consecutively.

upon the rise and fall of the external tide water; and of this action, the most essential circumstance is the interior level, corresponding with the known exterior level, at any given instant of the flood and the ebb. This being once determined for all points of the tide, all the conditions which can become the subject of inquiry, such as the head of water in action at each instant, the velocity, the duration of efflux and influx, &c., can easily be ascertained. The variation of the level of the interior water surface clearly depends, in addition to the variation of the level of the tide outside, 1st, on the interior area, and, 2nd, the dimensions of the opening by which it communicates with the sea. Assuming, for a moment, any relative levels of the interior and exterior water, the quantity flowing in or out will evidently depend on the difference of level, and on the dimensions of the opening; while at the same time the amount of variation produced in the level of the interior, by the influx or efflux of a given quantity, must be inversely proportional to the area of the inclosure. When the area to be filled, or emptied, is very small, in comparison with the opening, as in the instance of an ordinary dock with the gates open, the rise and fall inside will practically correspond with that outside, and no perceptible head will accumulate. On the other hand, supposing its extent to be very great compared with the opening, as, for instance, the extent of the Mediterranean compared with the Straits of Gibraltar, it is plain that its level would remain practically unaffected by the rise or fall outside. All practical cases lie between these extremes, and the less the area in proportion to the opening, the greater the variation of the interior water-level must be, in comparison with the rise of the external tide.

As the laws of the velocity of water flowing under various conditions are mostly capable of expression by convenient formulæ, it might, at first sight, appear easy to arrive at a general expression applicable to all such cases as the one under consideration; and, that by its means the interior height, at any given time, might be expressed in terms of the exterior level of the flood, or ebb tide, the dimensions of the opening, and the area of the interior water surface. But the Author considers this unattainable, and that if such a general expression could be found, it would be exceedingly complex and inconvenient for calculation. In preference he recommends the method referred to, of which the following are the details.

By means of a plan and levels furnished for the purpose, the areas of the several interior water surfaces were computed (Table 1), from 4 feet above low-water spring-tide, that being the datum from which all heights are reckoned, and which was the lowest level of the land to be reclaimed, at intervals of 1 foot, to a height of 15 feet, or to high-water level.

Table 1.

Height above Low Water.	Area.	
Feet.	Acres.	Square Feet.
4	342	14,900,000
5	1,075	46,700,000
6	1,860	81,000,000
7	2,600	113,000,000
8	3,720	162,000,000
9	4,570	199,000,000
10	5,460	238,000,000
11	6,150	267,000,000
12	6,350	277,000,000
13	7,000	304,000,000
14	7,350	320,000,000
15	7,350	320,000,000

Table 2 (page 171) exhibits the discharge, in cubic feet per minute, through a rectangular opening, for each foot of its width; the bottom being at the level of low-water spring-tide, and the heights of the water on either side being measured from that level. The discharges are taken from Tables 1 and 2 of Beardmore's "Manual of Hydrology,"[1] in the following manner:—

Let the heights, for example, be 15 feet on one side, and 6 feet on the other, giving an effective head of 9 feet. The discharge due to the upper 9 feet is taken as that of a weir or overfall, and is found from Table 2; but, as this table does not go beyond 3 feet, the required number is found by taking eight times the discharge due to a quarter of the head. This is merely extending the limits of the table, according to the formula from which it is computed. Thus a quarter of 9 feet is 2·25 feet, the discharge from which for each foot of width of a weir is 722·25 cubic feet per minute; and eight times this, or 5,778 cubic feet per minute, is the discharge due to a head of 9 feet.

The discharge through the lower 6 feet, corresponding to 9 feet head, is taken from Table 1; the mean between the columns C and D being taken for the velocity, which being multiplied by the depth, will evidently give the discharge for each foot of width. In column C the corresponding quantity is 1,350, in column D 900, and hence the mean is 1,125, which multiplied by 6 gives this part of the discharge to be 6,750 cubic feet per minute, which, added to the 5,778 before found, gives 12,528 cubic feet per minute, for each foot of width, or the quantity given under the greater height of 65 feet, and opposite the lesser height of 60 feet.

If the mean linear velocity of discharge is required, this is

[1] "Manual of Hydrology," by Nathaniel Beardmore, Civil Engineer, London, 1862.

TABLE 2.

INFLUX OR EFFLUX DISCHARGE in Cubic Feet per Minute, corresponding to any Heights H and h, of which H is the greater, for each Foot of Width of Opening, the Bottom being supposed to be at Low-water Level.

H =	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
$h = 0$	214	605	1,112	1,712	2,392	3,143	3,963	4,841	5,778						
1	..	589	1,135	1,762	2,462	3,231	4,061	4,955	5,901	6,903					
2	..	..	964	1,665	2,412	3,212	4,070	4,979	5,947	6,961	8,028				
3	..	..	..	1,339	2,195	3,062	3,962	4,909	5,897	6,939	8,021	9,153			
4	..	..	..	..	1,714	2,725	3,712	4,712	5,748	6,815	7,931	9,081	10,278		
5	..	..	..	..	..	2,089	3,255	4,362	5,462	6,587	7,733	8,923	10,141	11,403	
6	..	..	..	..	..	..	2,464	3,785	5,012	6,212	7,426	8,651	9,915	11,201	12,528
7	..	..	..	..	..	..	..	2,839	4,315	5,662	6,962	8,265	9,569	10,907	12,261
8	..	..	..	..	..	..	..	..	3,214	4,845	6,312	7,712	9,104	10,487	11,899
9	..	..	..	..	..	..	..	..	..	3,589	5,375	6,962	8,462	9,943	11,405
10	..	..	..	..	..	..	..	..	..	..	3,964	5,905	7,612	9,212	10,782
11	..	..	..	..	..	..	..	..	..	..	..	4,339	6,435	8,262	9,962
12	..	..	..	..	..	..	..	..	..	..	..	..	4,714	6,965	8,912
13	..	..	..	..	..	..	..	..	..	..	..	..	..	5,089	7,495
14	..	..	..	..	..	..	..	..	..	..	..	..	..	..	5,464

obtained by dividing the discharge as above obtained by the greater of the two heights, minus one-third of the difference between them, which will be about the height of the surface at the opening. If the total discharge is required, it is found merely by multiplying the discharge as above found by the width of the opening. Lastly, if the rise or fall per minute of the water surface inside is required, it is found by dividing the total discharge as last found by its area.

These Tables being prepared, the diagrams (Figs. 1 and 2, p. 173) were next constructed.

Fig. 1 shows, by the continuous black curved line, the rise and fall of a 15 feet tide, according to the Admiralty Form given in Table 40, of Mr. Beardmore's "Hydrology." The abscissæ of this curve show the time from low water, and the ordinates the height of the tide. The small circles show the results of an observation of the rise of a 17 feet tide, and the fall of a 14 feet tide, in the immediate neighbourhood, reduced for the purpose of comparison, in the proportions of 17 and 14, to 15 respectively. They are seen to agree very fairly with the curve; and it was considered that the average was probably better represented by it than by any particular observation.

The continuous black curved line on Fig. 2 shows, similarly, the rise and fall of an 11 feet tide.

Now, supposing the opening in the embankment to be sufficiently wide to drain out all the water at each tide, it is evident that the flood must rise to the 4 feet level before any quantity of water worth notice can begin to flow in, since the capacity of the interior below this level is altogether insignificant. At 4 feet, then, the influx commences, and its progress, and that of the subsequent efflux, for certain given widths of opening, is shown by the several other curves on Figs. 1 and 2. The construction of these curves is the chief peculiarity of the process, and, for want of a better term, it may be called a method of 'graphic integration,' since, by its means, results are obtained graphically, which it would require the application of the integral calculus to obtain analytically.

It is very usual to represent any previously determined relation between two variable quantities by a curve, of which the abscissa is proportional to the one, and the ordinate to the other; but, in the present instance, the relation between the variable quantities is the thing to be discovered; and it is obtained by constructing the curve, while the relation between its abscissa and ordinate remains still unknown, from a knowledge of the ratio of their respective variations, as a function of the ordinate itself.

This will be best illustrated by an example. Let 8, 9, 10 (Fig. 3, p. 174) represent a portion of the tidal curve, as before described, the figures indicating the number of feet of its rise, and

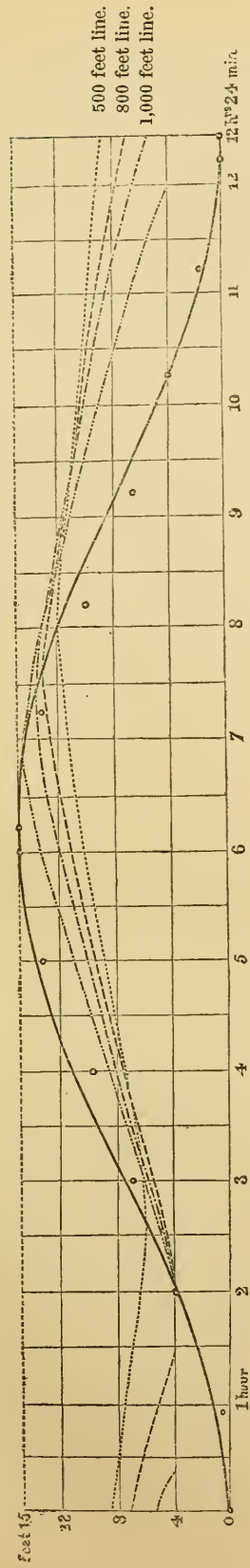

500 feet line.
800 feet line.
1,000 feet line.
12h 24 min.
Feet 15
12
8
4
0
1 hour
1
2
3
4
5
6
7
8
9
10
11
12

Fig. 1.

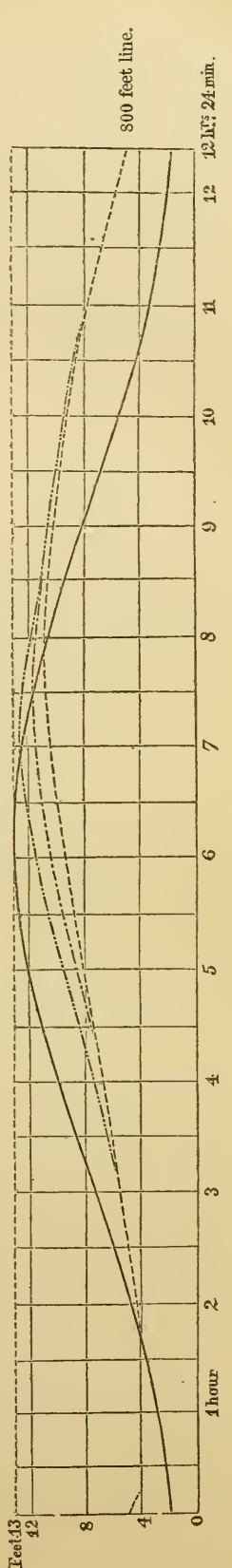
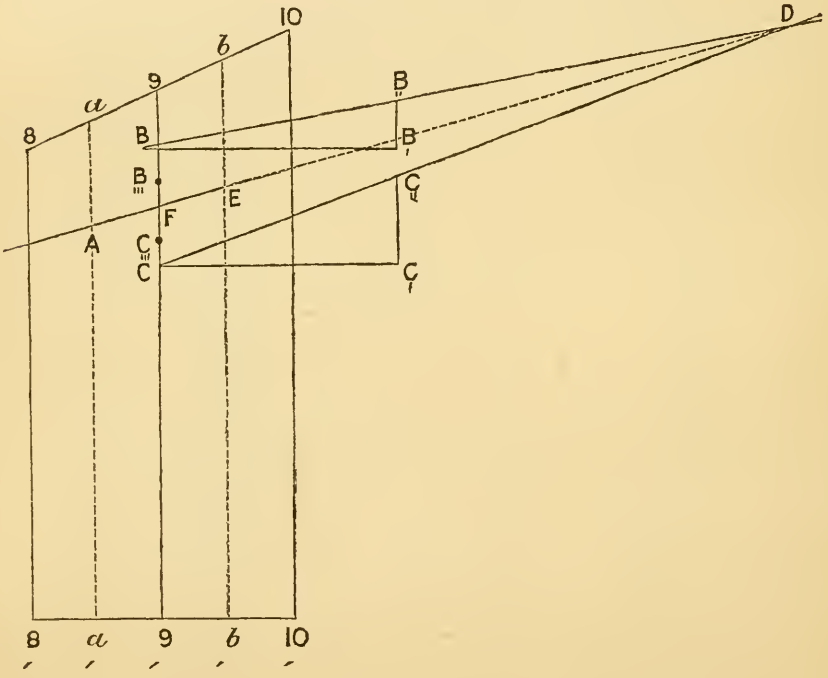

800 feet line.
12h 24 min.
Feet 13
12
8
4
0
1 hour
1
2
3
4
5
6
7
8
9
10
11
12

Fig. 2.

the horizontal distances the intervals of time. Draw two other ordinates, $a\,a_{,}$, and $b\,b_{,}$, half way between those at 8, 9, and 10, and therefore showing the heights of the tide at the half intervals of time. Let it be assumed that, by some means, the curve representing the rise of the interior water has been traced as far as the point A, and that it is required to prolong it. For this purpose it is further assumed, that the rate of rise of the interior surface, whatever it may be, will continue uniform for the interval of time expressed by $a_{,}\,b_{,}$. Take then two points B and C in the next ordinate (from 9 to $9_{,}$) such that the prolongation of the curve

Fig. 3.



must evidently pass between them, and compute what the rise of the interior water surface for a given unit of time must be, first on the supposition that this surface is at B, when the tide is at 9, and next that it is at C, when the tide is at $9_{,}$. This can be done with considerable exactitude by means of the hydraulic tables before mentioned. If then $B\,B_{,}$ and $C\,C_{,}$ be set off equal to the unit of time, as, for instance, a minute, on the scale of the abscissæ, and $B_{,}\,B_{,,}$, $C_{,}\,C_{,,}$ be set off equal to the corresponding rises of the surface, on the scale of the ordinates, it is obvious that the lines $B\,B_{,,}$ and $C\,C_{,,}$ will be the directions of the tangents to the curve showing the rise of the interior water;—the first on the supposition that it passed through B, and the other on the supposition that it passed through C. It is, moreover, evident, that in the present case, the rise of $CC_{,,}$ will be more rapid than

that of B $B_{,,}$, and that therefore B $B_{,,}$ and C $C_{,,}$ being prolonged, will meet in some point D. If A D now be joined, cutting the ordinate 9 to $9_{,}$ in the point F, it is obvious that the portion of it, A E, lying between the ordinates $a\,a_{,}$ and $b\,b_{,}$, must represent the rate of rise of the surface more nearly than either B $B_{,,}$, or C $C_{,,}$, for the interval of time between them; and that on the assumption of the uniformity of the rise during that interval, it would form, approximately, a portion of the curve, showing the rise of the interior water, which curve will thus have been prolonged from A to E. The point F being now found, a fresh calculation will verify whether the rate of rise shown by A E corresponds, with sufficient exactness, to the interior height F; and if this is found not to be the case, two new points $B_{,,,}$ and $C_{,,,}$ may be taken nearer to F, on each side, and the process repeated, so that any required approximation to exactitude may be by this means obtained.

If, besides this, it should appear that the assumption of uniformity of rise, over so long an interval of time, was not admissible, which, if so, would be indicated by a palpable angle at A, between the directions of the old and the new portions of the curve, this would be remedied by lessening the interval operated upon, that is, by taking the original three ordinates of the tidal curve at intervals of 6 inches, or 3 inches of rise, instead of at intervals of 1 foot.

A doubt may be, à priori, entertained as to whether this method of constructing the curves would lead to a reliable result. There can be, however, no difficulty in verifying them after they have been constructed; and if throughout the length of each, the rate of rise or fall, which for a sufficiently small interval may be regarded as uniform, be found to represent truly the rate of rise or fall of the water surface, due to the interior and exterior heights at the time, it must be manifest that such a result would be incompatible with any other supposition, than that its ordinates throughout correctly indicate the heights of the interior water.

There are, however, for each assumed width of opening, an infinity of curves that will fulfil this condition, according to the heights originally assumed; but amongst them there is only one consistent with permanency, and the test of this is, that after a full period of a tide, it should return to the same level. If it does this, it is obvious that in the succeeding tide, all the circumstances being exactly the same, it will repeat itself, and will continue to do so, as long as the rise of the exterior tide-water remains unaltered. If it does not return to the same level, its motion during the next tide will be indicated by a different curve, and a different one will again be described at each succeeding tide. Each new curve, however, will approach more nearly than the previous one to

a return into itself, and after a very few tides the permanent limit will, practically speaking, be reached.

It remains only to notice the indications afforded by these curves when established. The 1,000 line on Fig. 1, traced by the method described above, the starting point being the 4 feet level of the tidal curve, shows the rise and fall of the interior water corresponding with an opening of 1,000 feet in width, having its bottom at the level of low water. It is obvious that the state of things indicated by this curve will recur at every tide, as it appears that it falls to the 4 feet level more than an hour and a half before the succeeding flood tide reaches that level; so that the interior will be completely drained out during this period, and the influx will recommence from the ground, or 4 feet level every tide. Following this curve from its commencement at the 4-feet level, it appears that the maximum difference of level, or exterior head, is attained at five hours after low water, and amounts to about $3\frac{1}{2}$ feet—the outside height being then about 14 feet, and the inside 10·5 feet. The velocity due to these heights is 680 feet per minute, or $7\frac{3}{4}$ miles per hour, which may, therefore, be taken to be about the maximum velocity of influx. Following the curve further, it attains its maximum height at $7\frac{1}{4}$ hours from low water, where it comes to a balance with the ebb tide outside, which has by this time fallen 1·25 foot. At this point it crosses the tidal curve, showing, that the preponderating head of water is now transferred to the interior. This head rapidly increases as the tide continues to ebb, the large interior area, now that the higher level is on that side, not allowing the surface to follow the fall of the ebb so quickly as it did the rise of the flood. The maximum head appears to be attained about eleven hours from low water, when it amounts to about 6·75 feet, the interior and the exterior levels being 8·25 feet, and 1·5 foot respectively. The velocity of discharge due to these levels is 870 feet per minute, or 10 miles per hour, which may therefore be taken to be about the maximum velocity of efflux. The head now begins to diminish rapidly, owing to the slower rate of fall of the ebb tide, and the smaller area of the interior surface, which enables the interior fall to gain on the tidal fall. About twenty minutes after low water, the inside water is down to the 4 feet level. Beyond this it would be useless to carry the investigation of its motion, as the quantity of interior water remaining is insignificant, and may, for the present purpose, be considered to stand at the 4 feet level till the next flood arrives at that level, and the same train of circumstances recurs.

The 500 line on Fig. 1 represents, in a similar manner, the rise and fall of the interior water for an opening of 500 feet in

width. In this case it is seen, that the interior water is unable to flow out before the rising of the succeeding flood, which meets it at the 6 feet level at about 2 hours 26 minutes after low water, and recommences to flow in. The maximum exterior head is attained about $5\frac{1}{2}$ hours after low water, at which time it is 4·75 feet, the heights being respectively 14·5 feet and 9·75, and the velocity, consequently, 800 feet per minute, or 9 miles per hour. The maximum interior head is at about 12 hours after low water, when it is about 8·75 feet, and the corresponding velocity 950 feet per minute, or 11 miles per hour.

The 800 line on Fig. 1 shows the rise and fall for an opening of 800 feet. The maximum exterior head is at 5 hours from low water, the heights being respectively 14 feet and 10 feet, and the velocity $8\frac{1}{4}$ miles per hour. The maximum interior head is at $11\frac{1}{2}$ hours, the heights being respectively 8·4 feet and 0·6 foot, and the velocity $10\frac{1}{2}$ miles per hour. This line falls to the 4 feet level about 1 hour 22 minutes after low water, nearly three quarters of an hour before the flood tide rises to that level, showing that the interior water would be completely drained off at each tide.

The 800 line on Fig. 2 shows the rise and fall for the same opening with an 11 feet tide. The heads, and velocities, being manifestly less than in the case of the high tide, do not require further investigation.

It would therefore, appear, in the case under consideration, that about 800 feet of aggregate width for the final closing places would be sufficient, though not much more than sufficient, to allow of the complete drainage, at each tide, of the interior water. It would also appear, that these closing places must be so constructed, as to be capable of resisting the scour of a current of $10\frac{1}{2}$ miles per hour, which would be the minimum efflux velocity, when the banks were closed up to them.

There remains still to consider, how the junction of the banks with these closing places is to be effected. It is evident, supposing the banks to be carried forward at their full height like a railway bank, that as the open space left between them, for the passage of the water in and out, is diminished, the velocity and scour would increase; and when this open space became very small, so that there was little more than the 800 feet originally provided, the scour against the ends of the banks, and the ground between them, would be very nearly the same as that through the closing places; and although the latter, having been constructed with special reference to resisting such a scour, would suffer no injury from it, there would obviously be a great deal of difficulty, and risk of failure, in carrying forward an embankment exposed to its action. To avoid this difficulty, it was intended to stop the carrying on of the banks to their full height, as soon as any

injurious amount of scour should begin to show itself; and to make up the intervals then remaining, over and above the final closing places, by bringing up the banks, as evenly and simultaneously as possible, in horizontal layers.

In order to obtain a distinct notion of the action of the water during the carrying up of these last remaining portions of the banks,—the supposition was made, that the space so to be made up was 1,200 feet in length. This being in addition to the 800 feet to be left for final closing, there would be altogether open, for the flux and reflux of the water, 800 feet, reaching down to low water mark, and 1,200 feet reaching down to the 4 feet level. The line shown thus — ·· — ·· — on Fig. 1, denotes the rise and fall of the interior water under these circumstances, corresponding with a 15 feet tide.

The line shown thus — ·· — ·· — on Fig. 2 denotes the rise and fall corresponding with an 11 feet tide, on the supposition that the embankment in the 1,200 feet space, had been brought up, in horizontal layers, to a height of 4 feet above the ground, or 8 feet above datum. The dotted line thus — · — · — on Fig. 2 shows the rise and fall on the supposition that the horizontal layers had been brought up 3 feet more, or to 11 feet above datum.

The inferences drawn from these lines were, first, that 1,200 feet would be too small an interval, as the efflux velocity would reach 8 miles per hour, which would produce too great a scour for earthwork to resist; next, that the raising of a bank, in horizontal layers, would have the effect of continually diminishing the velocity of the water flowing over it, so that, if any injurious action occurred, it would most likely be at the commencement of the operation; and that if it did not then take place, no great apprehension need be felt for the future stages of the work, even though it should extend over several tides. The closing should be carried on during the period of neap tides, and be completed in as few tides as possible.

The final closing of the 800 feet of opening originally established, would have to be done in a single tide, so as permanently to exclude the water from the interior; but as all the arrangements for this would have been made from the commencement, and as the condition of the work would be such as to admit of waiting if necessary, for the most favourable opportunity, there could be little doubt of its being successfully accomplished.

The general results of the inquiry showed that from 700 feet to 800 feet of opening would have to be originally established for final closing; and that the last portions of the banks—probably amounting, in the aggregate, to between half a mile and a mile in length, would have to be carefully and simultaneously brought up in horizontal layers.

An approximate rule, suggested by this investigation, for the aggregate width of the final closing places, would be to allow 1 foot of width for every 10 acres of the area to be reclaimed; and this may be assumed as a basis for commencing a similar inquiry with reference to any other case.

It has been already remarked, that in proportion as the width of the opening of communication between the tide and the interior water is diminished, the variation of the level of the latter is diminished also; and that when the opening becomes very small indeed, in proportion to the interior area, the variation of level in each tide becomes imperceptible and may be treated as a constant quantity. This would be indicated, in such a diagram as Fig. 1, by a diminution in the vertical range of the curve, corresponding with the diminished width of opening, and, the limit towards which the curve would tend, on continuing to diminish the width of opening, would be a straight horizontal line.

The height of this fixed level is simply a function of the rise of tide, and may be found without much trouble, for any particular rise—by trial and error—the condition being obviously, that the efflux and influx in each tide should be equal. In the case of a 15 feet tide, it lies at about $9\frac{1}{2}$ feet above low water, and in most cases would probably be found to lie at between three-fifths and two-thirds of the total rise of the tide; the bottom of the opening being always supposed to be at low-water mark.

The Paper is illustrated by several diagrams, from which Figs. 1, 2, and 3 have been compiled.

[Mr. G. W. Hemans

Mr. G. W. Hemans said, having requested the Author to make these calculations, he might remark that at the mouth of the River Thames, on the Essex coast, there were two large foreshores, which had frequently been the subject of projects for reclamation. These were the Maplin Sands and the Dengie Flats. The latter comprised an area of about 7,000 acres, entirely covered with mud, which had gradually accumulated to a depth of from 6 feet to 8 feet, or 9 feet, and the surface of which was in no place more than 6 feet under high water of spring tides. It was now in a fit state for reclamation, and capable of being converted into valuable territory; but an embankment built upon such a site, and of a size requisite for so extensive an area, would be liable to considerable subsidence, while great care would be necessary in the final exclusion of the sea. Now, though he had constructed works of that nature, and had heard some valuable Papers read on the subject, he had felt the want of a scientific and practical statement of the best and most systematic way of closing the banks. Hitherto, engineers and contractors appeared to have followed no fixed method. Sometimes the embankments were brought up in long 'tips,' from both ends, and at others by side cuttings and hand-work. But in most cases, the closing, in whatever way effected,—whether by fascines, which was the Dutch method, or by rubble stones, or straw, or by any other means,—was done so hastily and badly, that there had always been serious loss; the rush of water carrying away the ends of the embankments and the foundations upon which they rested.

It had occurred to him, that it was desirable in the construction of this large work, to have fixed places, for the purpose of draining out the water; that these outlets should be provided with stone sides and proper aprons, and where necessary, with inverts; and that the openings should be of such a width, that at every ebb tide the inside area would be dry, so that the work of raising the banks could be carried on. Each opening should, in the first instance, be converted into an apron of stone, of sufficient size to resist the velocity of the water; and within that area stone piers should be built, or strong wooden piles be driven, in such a way that frames could be let down, in a similar manner to that so successfully employed by Mr. Hawkshaw in the case of the Middle Level,[1] or else planks should be fitted with grooves, and be let down at low tides to prevent the great loss from scour. Considering these outlets indispensable, he had requested the Author, whose mathematical powers were well known, to calculate in what way the proper size of an opening ought to be laid out for an area of 7,000 acres. It was for this area, therefore, that the calculations

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxii.

had been made; but the work had now been commenced on a part only of the Flat, as it had been decided, and in his opinion wisely, to divide the operation into ten, or twelve sections. He considered the calculations had led to a successful and practical method of arriving at the required result; some of them, however, being very scientific and abstruse, a few words of further explanation might be acceptable. The Author's method was to assume openings of various sizes, beginning with a total width of 1,000 feet; but that was found to be superfluous, and ultimately he concluded, that an opening of 800 feet would be sufficient to drain out the interior area at every tide. Then, by means of the tables of the motion of water, he constructed curves, showing the rise of the tide with its successive rates, from minute to minute, and from hour to hour. In Figures 1 and 2, the times were shown along the base lines, which afforded a scale of hours and minutes. The vertical ordinates showed the amount of rise for every hour and every minute, and hence, the difference between the exterior and the interior curves showed the difference between the water inside and outside the embankment, and thus the velocity of the ingress, or egress of the water was ascertained. The velocity of exit, from this area of 7,000 acres, with a tide of 15 feet, amounted to 10 miles per hour. Works to resist this efflux would require to be of great strength, and the consideration of this fact would serve to guide the engineer in the construction of an outlet in such a case. That result had been obtained by calculation, and was important; he believed the curves laid down were correct, and that the Paper was of great value.

It was not his intention to discharge the whole of the tide through one outlet, but to make, on the most depressed parts of the foreshore, four, or five outlets, each from 100 feet, to 200 feet wide, and to close them at neap tides, when the head of water was smallest.

Mr. VIGNOLES considered the principles laid down in the Paper were sound and the calculations correct. No doubt the velocity of the water, flowing in through any of the openings, could be ascertained, and the quantity and the velocity of the discharge, through the same openings, could also be found, by the difference in the rise of tide filling the area within. It was further possible to ascertain, whether it would be more prudent to effect the stoppage at a number of small openings, or at a single large one—for all these matters merged themselves into the one question of how the banks were to be closed, or the breaches stopped. If, by the Author's formula, the velocity of water flowing out and in were known, the forces to be dealt with would also be known. Believing these calculations to be correct, he would now describe a practical mode of stopping breaches, adopted in countries where such accidents

frequently occurred, and which he himself had executed with success. The method to which he alluded, was to close the breach horizontally, by gradually shallowing it from the bottom of the opening; watching the progress of the ebb and flow through the breach, fortifying each layer of material as it was laid, and so gradually filling the breach. When the closing was executed vertically, which must always be done in a more, or less, rapid manner, there was considerable danger from the rush, and velocity of the water, the velocity being in proportion to the narrowness of the opening; but by raising the bottom, the velocity, so far from being increased, was diminished.

Mr. A. Giles said, the reclamation of land should be considered as a commercial question. Such undertakings involved risks, and no Engineer should attempt them without providing, in his estimates, a large sum for contingencies. The value of 7,000 acres of reclaimed land, at £20 per acre, (and this was a high price for it at first,) would be £140,000. Now an ordinary bank 9 miles long, 12 feet high, and 12 feet wide on the top, with a slope of 6 to 1 on the seaward side, and $1\frac{1}{2}$ to 1 on the inside, would require 1,200,000 cubic yards of soil; but in the particular locality under consideration the mud was 6 feet and 8 feet deep; therefore the amount of soil required would be much increased. Assuming, however, the quantity at 1,200,000 cubic yards, being tide work, it could not be done at less than 1*s.* per yard, and the cost would be £60,000 without allowing for contingencies. If a lighter description of work were substituted, with slopes of $1\frac{1}{2}$ to 1 on each side, reducing the cubical contents of the bank one-half, the entire expense would be nearly the same, because the bank would then require to be paved on the sea slope at a cost of 4*s.* per square yard. If this bank were closed with one opening of 800 feet, with a current running through it at 10 miles an hour, he did not think that £80,000, the remainder of the estimated value of the land, would pay for it. He could, therefore, readily conceive, that there was some hesitation on the part of the projectors in proceeding with the work, and that instead of enclosing the entire area of 7,000 acres with one bank, it had been decided, as an easier and more economical mode of proceeding, to divide it. He agreed that the proper way to close the opening in the bank was by gradual raising from the bottom.

Mr. G. P. Bidder, Past-President, said that, though the calculations in this Paper were of considerable value, he thought there were elements to be ascertained, which were very difficult of determination; for the quantity of water flowing in and out of an opening, at different tides, was so exceedingly variable, as to defy any ordinary power of mathematical analysis. As regarded the economic view of the question, though he could not consent to treat

it as being purely of a commercial nature, he admitted that certainly the most expensive way of acquiring land was by attempting to reclaim it from the sea. With respect to the extent of land to be comprised in one operation, he thought enclosure works of less than 800 acres, the area usual in Holstein, would not be remunerative, and that from 1,200 acres to 1,500 acres was the utmost extent which ought to be undertaken at one time. Beyond that area the difficulty of closing became almost insurmountable. Nor should the surface of the tract to be reclaimed be more than from 3 feet to 4 feet, under the level of high water. There were, however, on the banks of the River Thames large tracts of enclosed lands, marshes of great fertility, lying at a level of about 7 feet under high water; and in the fen districts of England, particularly in the counties of Bedford and Lincoln, some of the land was from 11 feet to 14 feet, under high-water mark. It was to be regretted that there were no authentic records of the manner in which those vast reclamations had been effected. There was, however, evidence to show, that the works had been executed in detail, from 1,000 acres to 1,200 acres, having been probably taken in at one time. The desirability of obtaining reliable information respecting the mode of executing these works would be the more strongly felt, by recalling to mind the breach which had occurred at Dagenham, and the arduous labours involved, as well as the outlay required, in the reconstruction of the bank.

As regarded the method to be adopted in closing the banks, or breaches, although driving piles, and dropping planks between them might be available in one particular situation, yet, in most cases, it was an expedient of all others likely to be disastrous in its results. In Holland, when the proper width of opening, due to the area of land to be enclosed, had been ascertained, the work was brought up, stage by stage, with the best materials of the district, protected by stonework and fascines, and carried on by a population accustomed to the work. Enclosures were thus easily effected, but considerable difficulty was experienced in protecting the embankments afterwards, from the storms which arose before the works were consolidated, or the herbage had grown to lessen the effect of heavy seas.

Mr. VIGNOLES believed, that the reclamations of land on the banks of the Thames had been made gradually, and in small enclosures, not of 1,000 acres, but of 100 acres or 200 acres. The reclamations in the fen counties, had, he thought, been effected in the same way. The works in Schleswig-Holstein, and Friesland, were all done in small 'Polders,' as they were called, many of them not exceeding 20 acres or 30 acres each. He had reason to believe, that authentic descriptions still existed of the manner in which the works in the fen counties had been carried out. There

were also records showing that Dutch labour had been imported for the purpose.

Mr. Leslie observed that Captain Perry, who had been employed in similar works in Russia, had made two attempts to stop the Dagenham breach of 1715 before he finally succeeded. The first was made by sinking barges, bundles of straw, and bags of clay; but this was ineffectual, as holes had been scooped out in the breach to the depth of more than 20 feet below low water. The second failed, because when the works were nearly finished, they were injured by high tides which overtopped them. The plan which ultimately succeeded was that of driving two rows of dove-tailed sheeting piles about 40 feet apart, with their heads about 1 foot above low water, filling up with hard stuff between them, and gradually raising the embankment; but Captain Perry took the precaution to form a large sluice on the higher ground, which could be easily closed, to which the water was led by a cut. In the estuary of the River Tay the embankments, for reclaiming land, were generally begun when the mud was raised about half tide level, or 8 feet below high water of spring tides.

Mr. J. Scott Russell, V.P., remarked that the method adopted by the Author had conquered many of the mathematical difficulties of a problem which had been pronounced almost insoluble. The process, of tentatively ascertaining the laws which regulated the rise and fall of water, was a very beautiful application of the integral calculus to the mechanical formation of a curve, of which the mathematical form was not known algebraically. It was a method of calculation suited for practical service in engineering; he had used the method of 'graphic integration' in calculating the qualities of ships, and it was generally of great value in solving problems connected with ship-building. With respect to the practical part of the subject, he generally concurred in the views which had been expressed, in regard to the necessity for previously making every preparation for closing the banks, instead of gradually approximating the sides of the opening by loose earthwork, the danger of which process was the almost insurmountable scour it created.

Mr. W. A. Brooks said, there was often a great difference in the high water levels of the sea and of the inland portions of an estuary. For instance, high water at Peterborough was 6 feet below the level of high water at Wisbeach. It was not at all places, where reclamations of land were made, that the tide rose to a great height. Where there was a considerable foreshore, between the open sea and the land to be reclaimed, enclosures were sometimes comparatively easy of execution. Although he concurred in the desirability of adopting the horizontal system of stopping breaches, or enclosing mud lands, he considered it would

be impolitic to close up embankments in the manner described in the Paper, so as to encounter a velocity of 10 miles per hour: it was even difficult to contend with a velocity of 2 miles per hour, or 3 miles per hour. Where a breach, or opening, was finally closed by successive lifts, as in Lincolnshire, and the tide was thus gradually excluded, proper sluices must be left for the future drainage of the lands. With respect to the materials to be employed, the clay should be carefully puddled, to prevent injury from scour, and in his opinion, putting large stones into the breach was calculated to retard rather than to advance the ultimate closing.

Mr. HEPPEL, in reply, said that Engineers would hardly attempt to contend with such velocities as those mentioned in the Paper; but, it must be remembered, this was not the subject it treated of. Its object was to give a practical method of ascertaining what velocities, and consequent backward and forward scours, would result from certain given conditions of rise of tide, width of opening, and area to be reclaimed, without entering into the mode of construction; and, he submitted, it could hardly be without advantage, to know beforehand, the velocities which would have to be encountered under given circumstances. It was for the Engineer to decide, whether he would attempt to deal with them, and if he resolved to do so, then, after a careful consideration of the peculiarities of the work in hand, it would also be in his province to determine what method of construction was most suitable. In the particular case which had been referred to, the land was protected from the full effects of the sea by a long foreshore, a mile in width, which would have a considerable influence in modifying the forces to which the works would be exposed. The process, described in the Paper, had been correctly alluded to as tentative; it was, in fact, tentative only. It was an attempt to elucidate a question incapable of being expressed by formulæ; it was a mode of treating geometrically, a subject that could not be treated analytically.

January 19, 1864.

JOHN ROBINSON M'CLEAN, President,
in the Chair.

The discussion upon the Paper No. 1,096, "On the Closing of Reclamation Banks," was continued throughout the evening, to the exclusion of any other subject.

January 26, 1864.

JOHN ROBINSON M'CLEAN, President,
in the Chair.

No. 1,103.—"The East Coast between the Thames and the Wash Estuaries.[1] By JOHN BALDRY REDMAN, M. Inst. C.E.

THE Author hopes that the following description of the Coast, between the Thames and the Wash, being similar in character to that given in 1852,[2] of the South Coast between the Thames and Portland, will be of interest to the Members; and that, in the course of the discussion, such further, and supplementary information will be elicited as will place on the records of the Institution a complete history of the changes which have taken place on that part of the English Coast, and an exact analysis of the causes from which they have arisen. On the South Coast the leeward progression of the shingle is up Channel, due to the preponderance of S.W. winds; along the eastern seaboard the motion is southward, owing to the greater influence of northerly winds, except along the north coast of Norfolk, towards the Estuary of the Wash, where the motion is in a westerly direction.

The greater development of tidal scour in the upper reaches of the river Thames, arising from an increased rise at high water, and a considerable fall at low water, both being due to the removal of old London Bridge, assisted by the progressive removal of shoals, is well known.

As a proof that dredging is required to a greater extent, it is only necessary to state the facts, that the depth at low water from London Bridge to Woolwich is generally 10 feet, thence to Daggenham it is from 15 feet to 20 feet, below to Purfleet it is from 20 feet to 30 feet, and thence to Gravesend it is from 30 feet to 40 feet, whilst below Barking Creek, Daggenham Shoal has only from 8 feet to 9 feet of water upon it.

Almost the entire area of Halfway Reach is encumbered with 'debris,' caused by breaches, that formerly occurred in the river walls; for with a mid low-water channel of 20 feet, both above and

[1] The discussion upon this Paper occupied portions of four evenings, but an abstract of the whole is given consecutively.

[2] *Vide* Minutes of Proceedings, Inst. C.E., vol. xi., pp. 162–204.

below, there is over the area of this reach only from 10 feet to 12 feet—in fact there is a submerged 'plateau' across the river. The same remark applies to Erith Reach, where with a depth of 30 feet above and below, there are shoals with only from 6 feet to 10 feet of water.

Though the general features of the Thames Estuary are familiar, many silent and scarce-recorded changes constantly occur along its shores. The sandbanks of its delta, from their nature, are subject to frequent change, and require constant supervision. The modern buoyage of the Prince's Channel, which has 6 feet more water than the Queen's Channel to the south of it, and which was formerly used by outward-bound vessels; the formation of a deep channel between the Girdler and Shingle Sand in 1861, and the subsequent shifting of the Girdler Light-vessel are cases in point.

The foreshores below Gravesend increase in width. The Blyth Sand, forming the southern boundary of the outfall of the river, called Sea Reach, is nearly 10 miles in length, by 1 mile in breadth at low water; and the Maplin and Foulness Sands below, on the north side, stretch out in one continuous belt of from 18 miles to 20 miles in length below Southend, with a breadth of from 2 miles to 4 miles at low water.

The low cliffs of London clay crowned with tertiary crag, between Leigh and Southend, are subject to falls, similar to those in the Isle of Sheppy of the same formation on the opposite shore.

At St. Osyth's, commences the great degradation of the coast to be presently noticed, the whole seaboard from the Colne to Harwich having experienced great change. St. Osyth's Priory forms a well-known sea-mark. Martello Tower No. 1 is within the marsh wall below the outfall of Brightlingsea Creek; No. 2 is situate on a low tertiary cliff; the small triangular fort or curtain in front is split up and has partially fallen, in consequence of the subsidence of the undercliff. St. Osyth, Wick, and Clacton marshes are defended by earthen sea walls; the sandy foreshore east of St. Osyth's Point has a small shingle 'full' at the top, backed by sandhills, and the shingle here commences to have two regularly-defined spring and neap 'fulls.' At Martello Tower No. 3, it runs out into a small point; and west of this tower a groyne, deeply buried in shingle, denotes a local increase; and eastward of the battery, there is a corresponding accumulation of beach increasing in breadth.

West of Lion Point or Eastness, a groyne on the sand foreshore, below the beach, denotes the retreat landward of the latter. The planked groynes and parallel breastwork, in front of Tower No. 4 and its battery, are further indicative of the waste of the shore; and Tower No. 5 is protected by similar defences.

Tower No. 6 is situate on the commencement of Clacton Cliff,

which is about 40 feet high, composed of loamy clay full of chines and slips, and it appears to have been wasted, to the extent of the breadth of the beach now lying at its base, during the last five years. The shingle decreases in quantity, and is occasionally entirely swept away, leaving only fine sand to resist the impact of the sea, groynes having failed to arrest the decay. At Holland Gap a timber parallel breastwork is also constructed. Clacton Cliff may be termed an intermixture of fallow and foreshore; for the yellow tertiary cliff, being subject to constant change, slides forward, leaving the former and meeting the latter.

At Holland the mere basements of the east buttresses of the church are left, indicating the site of the ruins. Here, on a mile of frontage, three acres of land have been lost in eight years, equal to a recession of 1 yard per annum; and the Scott (tax) on the 697 acres of Tendring Level, has risen from the average of 15*s.* 6*d.* per acre to 18*s.* 6*d.* per acre, and even to 25*s.* per acre.

Holland Haven has its outfall between Clacton and Frinton Cliffs. Here, a large crescent mole of shingle is driven by the volume of land water as far out as ordinary low-water mark, with a mean direction N.E. by N. and S.W. by S., and an average height of 10 feet above the shore. Holland Marsh wall is piled and faggoted, and groynes project at right angles across the foreshore.

The groynes, at the foot of Frinton Cliff, have not arrested the decay. Acres of undercliff lie below, as broad as the foreshore beyond, resembling a great railway 'tip' constantly progressing, with this difference, that the undercliff has a decreasing instead of an increasing bank; the falls take place in deep, rounded, indented scoops, leaving jutting points between.

Beyond Frinton Chapel Ruins, a portion of which is enclosed, at Burnt House Farm, a modern fall is close up to the house, the coast path is diverted down the slope of the undercliff; and a timber breastwork has been placed below, with groynes to check the progressive decay.

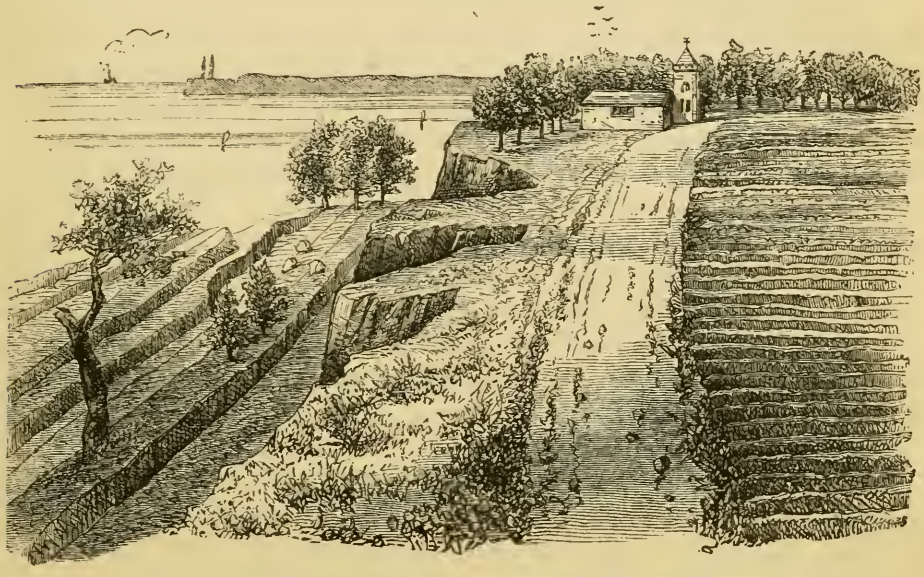
The Clacton, Holland, and Frinton Cliffs to the south of the town of Walton-le-Soken and the Walton cliffs northwards, have fallen coincident with all record; and sea walls and other defences have been erected during the last thirty years, to keep the sea in check, in front of the town; but immediately north, the low cliff is much eaten into, the sea wall standing out as a jutting point.

The Naze, towards the sea-mark, becomes one continuous avalanche of London clay and yellow sand; masses are deposited on the mud foreshore, with the grass of the season on them. 'Plattymore' forms the wide flat foreshore, which has no shingle and numerous groynes. One large slip is split up into laminæ, pre-

senting similar appearances to those at Warden Point, in the Isle of Sheppy.[1]

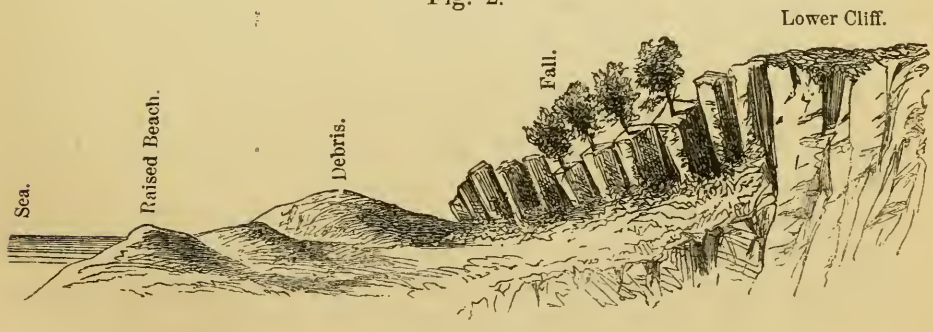
Another large slip may be particularized, where attempts have been made, by staking the top and draining the slope, to render it more permanent. Opposite the sea-mark the slips become extensive, in huge masses from 50 yards to 100 yards in breadth, and attempts are being made to drain the undercliff thus formed. A large portion of the crown of the Naze is formed of yellow 'crag.'

Fig. 1.



Isle of Sheppy. Warden Point. — Landslip.
View from W., looking towards the Reculvers.

Fig. 2.



Sectional Sketch.

[1] The fall at Warden Point is now much modified in appearance.—J. B. R. 29th June, 1865.

Fig. 3.

Terraces in hollow of Fall from Cliff.

For a distance of 2 miles from the Naze to Stone Point, at the entrance to Handford or Hamford Water, Walton and Stone marshes are protected by an earthen sea wall, with artificial works of a varied character, mainly faggoting, and rectangular groynes of wattling, requiring constant supervision. The arming of the sea slope of the wall is, in places, continuously of stake-piles set on edge, in parallel rows, above each other in steps. Seaward of the sand, yellow clay crops out, forming the foreshore, and London clay may be seen cropping through the sand, worn into forms like rocks; and, towards low water, near Stone Point, this water-worn clay appears in the form of black reefs. Here the sea is of a dark yellow tinge, over the shallows on each side of the entrance, sufficiently indicative of the waste going on, and of the material acted on.

Along the shore towards Stone Point, which thus derives its name, the sand becomes mixed with shingle, which ceases at the Point.

Handford Water forms a large tidal estuary of 3,000 acres area at high water, land-locked S.E. by the Naze, the neck of which peninsula at Walton is now only a furlong in width, and, like that on which Harwich stands, has become gradually thinner. The sea within the estuary during the ebb, retreats by numerous creeks, over the mud flats, the result of tidal deposit from the highly charged water; the creeks thus formed have left islands between their channels, and these have been gradually 'inned' as they reached neap level. The main outfall runs from near Thorpe-le-Soken in a N.E. direction to Stone Point, and into it run two main tributaries, Walton Creek in a N.N.W. direction, joining the main channel at Stone Point, and Oakley Creek in a similar direction, higher up above Pewit Island. These combined creeks preserve a low-water channel of 7 fathoms, of which the 'North Sea Pilot' says:—

"Hamford Water is particularly available in north-easterly gales for vessels which have lost their anchors, and are unable to fetch into Harwich Harbour."

The least water below, at the entrance, is 7 feet at low water, at

$1\frac{1}{4}$ mile below Stone Point. The foreshores on each side of these creeks, and around the islands, are formed by a thick deposit of soft black mud: this is one of the recommendations of the estuary, as a place of refuge for weather-driven vessels missing Harwich, and liable to go ashore.

Between Handford Water and Harwich there appears to be a constant struggle to maintain the frontage. The sea-wall in front of the Oakley and Dovercourt marshes is frequently breached, and, at such weak places, it is repaired with 'arming.' Groynes are thrown out from time to time, and drifted sand lies on the summit of the broad flat foreshore at the foot of the earthen sea-walls. About the centre of the bay the sea-wall, for some distance, terminates, the marshes being protected by the remains of a range of sand-hills driven into the head of the bay. Towards Dovercourt, the sea defences become a thin, badly-formed bank of clay, formed of material irregularly, and apparently, hastily dug out from behind, with faggoting defences seaward, and occasional groynes, the general direction of the wall, N.E. $\frac{1}{2}$ E., and of the groynes, E. $\frac{1}{2}$ S., presenting an acute angle in a N.E. direction, in which a small amount of sand and septaria pebbles collects at the top.

Southward of Dovercourt, the sea defences are more regular in character, of large rough Kentish rag-stone, between parallel rows of faggots, the sea-wall terminating with a projecting mole, or breakwater out on the foreshore, parallel to the shore, in advance of the old wall, which it overlaps; and in the bight thus formed there is a local accumulation of sand. North of this is a complete pier, of similar construction, running out at right angles to the shore, with a curved end, and between these two moles are three inclined groynes; in the intervening space between these works and Dovercourt, the wall is irregular in direction, with trees sunk in the foreshore to act as breakwaters, and there is a large amount of drifted sand and sand hillocks at the top. At the north end of the bay are two old counter-walls at the back of the sand-drift. At Dovercourt the clay cliffs again crop out, and are artificially sloped and protected at the base, by a stone sea-wall. The curved slope first put up by Mr. Bagshaw, about twenty-five years back, was breached in several places. in 1860. The paving having become worn at one part of the north end of this wall, from a breach having been neglected, about 50 feet of the entire wall fell in, and the sea breached into the clay behind, to the entire breadth of the esplanade.[1]

Towards the breakwater at Harwich, the sand of the foreshore

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[1] Since completely restored.—J. B. R. July, 1865.

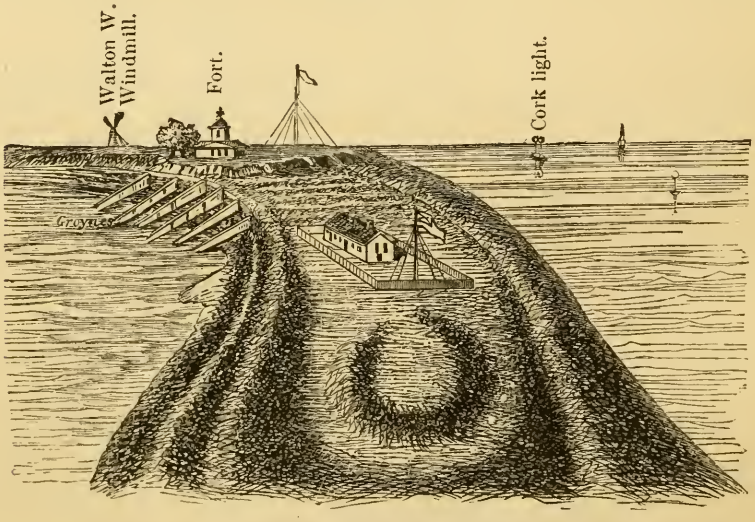
becomes mixed with fine shingle. Beacon Cliff appears to have first attracted attention about two centuries back, as may be seen by various papers in the "Philosophical Transactions." From a map of Harwich, of the time of Henry VIII. (Plate 2, Fig. 2), with forts proposed on Landguard and Beacon Cliff, there would appear to have been a large quantity of cement stones, (septaria) lying off Beacon Cliff, from whence so much has since been removed, and also off Landguard Point.

The Admiralty Chart of Harwich of the present day shows, that although scattered heaps of cement stone lie along the margin of Mill Bay, towards low water, none exist at Landguard.

In 1850, Beacon Cliff was artificially paved, and it forms the root of the breakwater. Along the north end of Mill Bay, as far as Mr. Bagshaw's boundary, the base of the cliff was artificially sloped and paved to 6 feet above high water, with a cess 10 feet wide, to form a promenade, and the clay of the cliff was formed to a slope above. Northward of the pier, it was treated in a similar manner Between the breakwater and the old Low Lighthouse, numerous groynes run out below the stone slope at its northern end, nearly at right angles to the wall, some slightly inclined northward, the sand being highest on the south or sea side.

Walton Creek, on the opposite shore to Harwich, forms the base on which has formed Lunger, or Landguard Point, (Plate 2,

Fig. 4.



Landguard Point.—View from S.W. Horn, looking E.N.E.

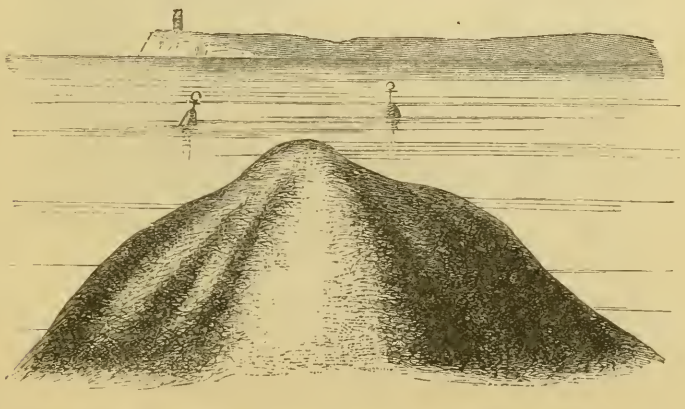
Fig. 3,) the shifting of which is traceable by indications existing on its surface, as well as by a comparison of the Cotton Maps, those by Collins of a subsequent period, the Ordnance Survey now thirty years old, and the Admiralty Charts of the present time. The fore-

shore, adjoining the Ferry, is mainly sand covered with shingle. The Fort stands on a low mound, which is being eaten into by the sea, and both north and south of the Fort, on the W. side of the Point, the shingle is retreating on the concave side. This has induced the erection of groynes, in the neighbourhood of the Fort, the upper ends of which have gathered considerable 'fulls' of shingle.

Southward, between the new Trinity House Light and the Fort, the bluff end of the overlap of the sea-beach from the point, is met with, trending inward. The entire area of the point, seaward of the Fort, is clearly an accumulation of sea-sand and pebbles, partially grass grown, the 'fulls' forming ridges parallel to each other, and the intervening furrows being distinctly traceable. The modern overlap, or trending inward of the Point, has so altered the bearings of the entrance, as to induce the maintenance of a third light, by the Trinity Corporation on the spit, which the old lights did not clear; and the subsequent entire discontinuance of the latter having been rendered necessary, new lights have been erected south of Dovercourt.

Fig. 5.

The Naze.

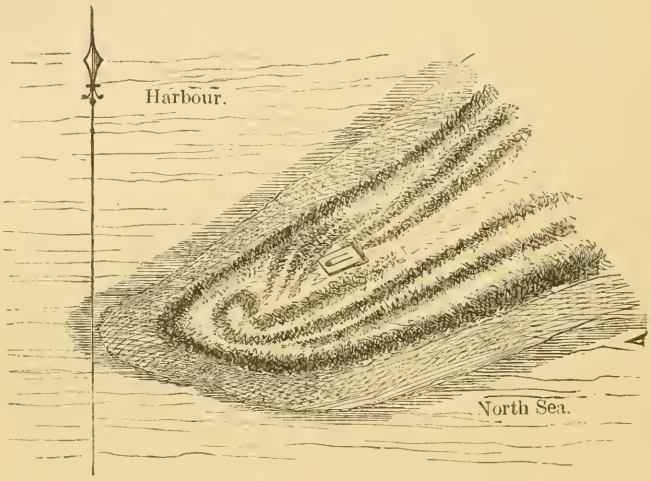


Landguard Point.—S.W. Horn, looking S.W. by S. towards the Naze.

The formation of Landguard is somewhat different to that of Dungeness and other similar formations, as it is at the extreme projection, formed of sand and small shingle, worn into a rounded hummock, with little cliff-like edges, by the varying action of the sea. Off the extreme S.W. point, with a strong S.S.W. wind, there is a complete cross sea. Here, as elsewhere, though mostly small and fine, the largest pebbles are cast up to the summit. The same remark applies to the east side of the point, where there is a long slope of fine sand and pebbles, crowned at the

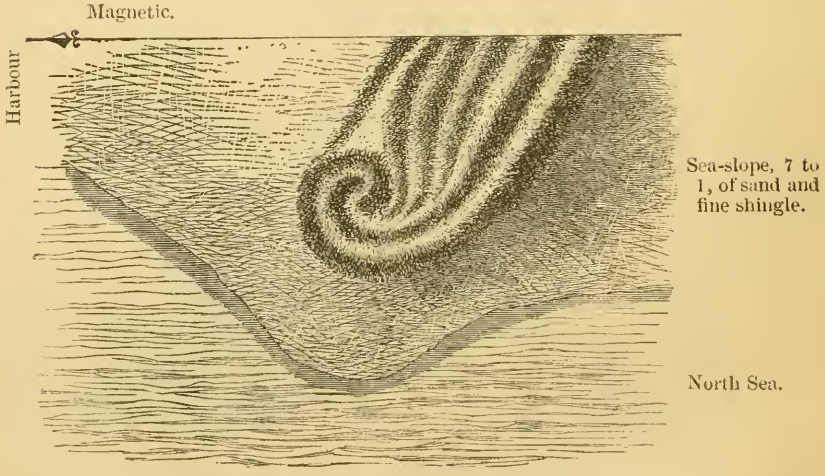
summit by a 'full' of shingle; the largest pebbles being between the crown and the grass-grown sand-drift at the back.

Fig. 6.



LANDGUARD POINT.—Outline of S.W. Horn.

Fig. 7.



LANDGUARD POINT.—Summit of Seaward End.

Between the Fort, and the new Light dwellings, the progressive westerly increase of the spit may be traced, in a series of parallel lines, marking its seaward extremity at various past periods. These meet the present margins in so rectangular a manner, as to show the way in which the wasting has proceeded eastward, and the increase, westward; the latter in effect resultant on the former, the successive rounded S.W. horns thus formed being intact. The rounded grass-grown 'fulls,' due south of the Fort, in a N. and S. direction, at right angles, nearly, to the immediate sea margin of

the point on the south side, show that the spit stretched much farther into the sea in that direction at an early period.

At the old graveyard, the easterly decrease is said, locally, to amount to from 500 yards to 600 yards in the last ten years. The burying-ground is now one-half gone; and the shore line intersects it on the diagonal; and as the entire square area is shown upon the Ordnance Survey, with a considerable belt of shingle beyond, an approximate idea of the decrease may be gained. In 1838, the distance, from the centre of the graveyard, to high-water mark, appears, by the Ordnance Survey, to have been ½ a furlong. This would give an average annual decrease of 4·40 yards. Martello Tower O., south of the graveyard, the site of which is now entirely covered by the sea at high water, was removed in anticipation of this decrease.

The present Fort was erected in 1718. On its harbour, or west side there has also been a local decrease of shingle, amounting, in the last three or four years to 10 yards, and coincident with this, great quantities are removed, for ballasting ships, under the authority of the Lord of the Manor. Three series of groynes have been successively erected for the protection of this military post, but though they created local 'fulls,' the recession proceeds N. and S. of them as before described. There would thus appear to be a wasting on each side of the Point, or a 'thinning' process going on, and a corresponding elongation of the S.W. extremity, which in forming in this direction, is quite churned up by the waves; and there is a constant alteration of sectional outline with varying winds. As at Dungeness and Langley Points, there is, in connection with the extension, an eating away, chiefly on the weather side; the whole tending to show that Harwich is lapsing towards the condition of a bar harbour.

The entire area of the spit, landward of the Fort is formed of parallel 'fulls' of beach, clearly defined, as at Pevensey (Langley Point); but the nucleus is covered with fine turf. Where cart tracks exist, the shingle crops out. The ancient 'fulls' are parallel to the high-land, and at an acute angle to the present sea-margin; parallel to which latter, between the Fort and Tower P., is a large sea-mound, grass-grown, and 200 yards distant from the present shore; precisely similar to those which are found at Sandwich, in Kent. This ancient mole, as much behind as the present shingle 'fulls' are seaward of Tower P., shows the variations of the spit to have been constant, and to have extended over very distant periods. From the high ground between Martello Towers Q., Lower Walton, and Tower N., at Walton Ferry, the manner in which the Point has been formed may be traced. Barriers of sand and shingle, driven along the shore from the N.E., have gradually enclosed Walton Creek, in all probability the site of the

ancient outfall of the River Orwell. The overlaps of each formation may be traced in a western direction south of the Creek. Against these, outer marginal belts in a more N. and S. direction have been formed, curving, in a horn-like form, at the end of the spit, into the harbour.

The erection of the stone groyne, or breakwater, on the west side of Harwich Harbour, has had no influence on Landguard Point; and the question arises, whether extensive groynes eastward of Landguard, or a deep-water pier east of Bawdsey, would be a more effectual remedy? This however is very problematical, as the various surveys of Harwich Harbour, as well as the observations on the Point given above, show, that the action is to a great extent local, viz., a 'thinning' and extension of the point itself, which could only be checked by works confining the existing marginal outline of the spit.[1] A comparison of early plans with the present Admiralty charts of this Harbour, will show the continued retreat of the shore on the west side of the entrance, and the local extension westward of Landguard Point, which however at one period extended further seaward in a south-east direction. This extension of the spit in a westerly direction, the late Admiral Washington estimated in 1848, to have been at the rate of 10 yards per annum, or 400 yards in the 40 years prior to his Report; and he demonstrated that the sea had gained 80 yards, in a direct line, on the opposite western shore, or at the rate of 2 yards per annum; and that along the Felixtow shore, the rate of loss was further accelerated by the wholesale removal of cement stones, which formerly were barriers to the ravages of the sea.[2]

Bull Cliff is formed by the out-crop of the tertiary sands N.E. of Landguard. It is about 40 feet high, with small sand 'dunes' at its foot, a shingle beach beyond, and a sandy foreshore. The cliff declines to the shore, west of Bawdsey Haven, where a very large accumulation of modern shingle is met with. The groynes to the south-west of the battery, in front of Tower T. are buried in shingle and sand, and those more recently constructed hold large 'fulls' of shingle.

The entrance on the west side of Bawdsey Haven is flanked by

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[1] By the Harwich Harbour Bill (10th May, 1865) a pier was proposed to be constructed on the Landguard inner beach, 1,200 feet N. of the Light dwellings or cottages, and extending in a west direction into the harbour 200 feet. The Harbour Conservancy Board have advertised for tenders for groynes, one to project in a south-east direction, 1,350 feet seaward of the Light dwellings, and another in the same direction 1,000 feet in length, at a point to the northward of the Fludyer's Arms inn, on Felixstow beach.

[2] The rate of progress still continues, the westerly tendency increasing, and the present S.W. extension of the spit defined on Plate. Fig. 3 was taken on the 3rd July, 1865.—J. B. R.

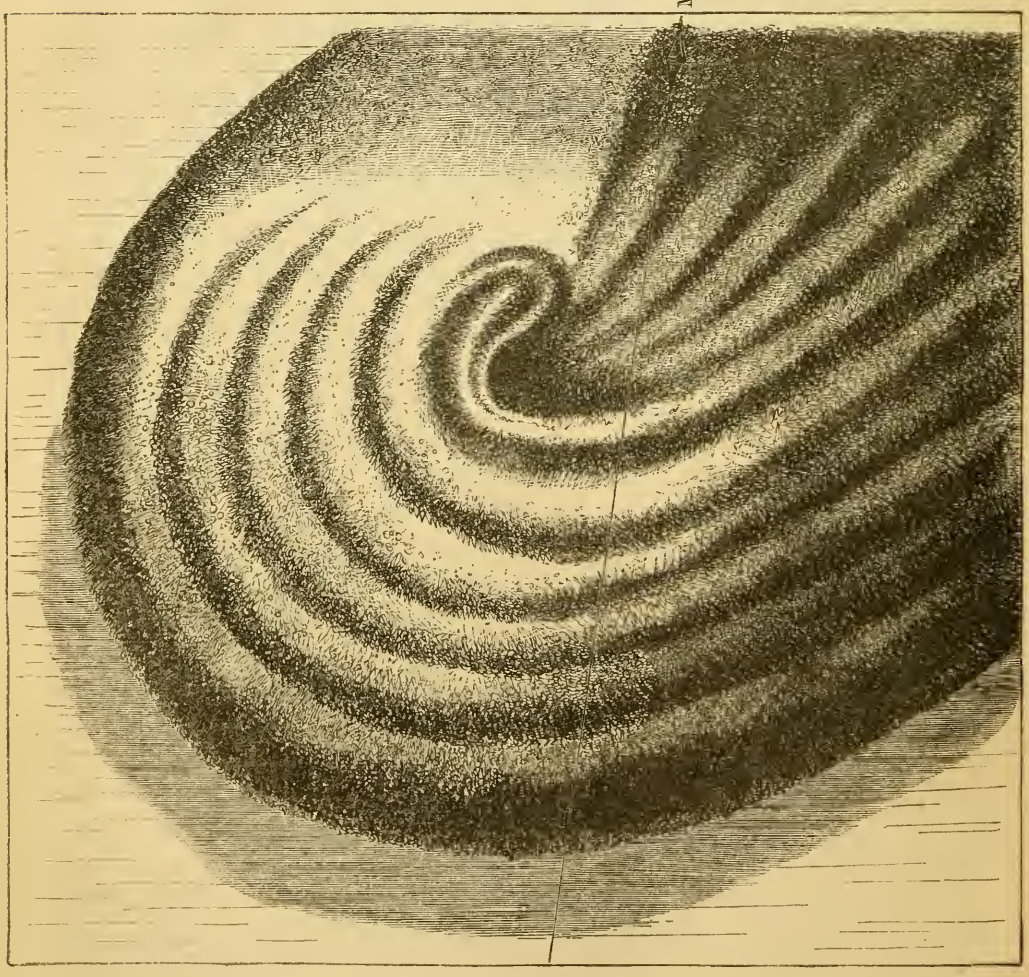
sand 'dunes' behind the shingle, in front of the salt marshes, in line with Towers T. and U., in advance of which is an immense accumulation of sand and shingle, 80 yards in breadth opposite Tower T. The shingle becomes steep on the curve into the harbour, and increases to a breadth of 150 yards between the two Towers. It is composed of seven series of parallel curved concentric 'fulls,' with a general direction N.N.E. The sand foreshore is hard and steep next the harbour's mouth. The moveable beacons on the crest of the beach, near Tower U., are sufficiently indicative of the fluctuating character of the entrance. Here, the shingle is reduced to 70 yards in breadth, with two modern 'fulls' in advance of grass-grown mounds. The modern 'fulls' tail round into the harbour on the west side, north of the houses adjoining the Ferry, in the usual horn-form, gathering inshore, above which is the western mud foreland of the River Deben. The east shore spit terminates in a similar manner immediately opposite. West of the haven's mouth, stretching far into the sea beyond the Black Buoy, may be seen an extensive triangular area of yellow shoal water; and immediately off the entrance two yellow island spits, dry at half-ebb, a prolongation of the beach from the north-east, through which the outfall waters cut intersecting channels. There is deep water to the west of these, trending round towards the coast line in a S.S.W. direction. Bawdsey Haven is available, as far as Woodbridge, for vessels up to 250 tons burthen, and of from 12 feet to 13 feet draught. The rise is 11 feet at springs and 7 feet at neaps, with 2 feet over the bar.

An extensive accumulation of drifted sand lies on the east side of the haven up to Bawdsey Cliff, which is about 50 feet in height, and falls much. The sea eats into the spit N.E. of the haven, and under the Cliff the shingle is narrow and thin, with a clay foreshore. Martello Tower V., formerly situate on the Cliff, has been pulled down, apparently in anticipation of the continued fall of the Cliff; and the battery which formerly existed outside of it is also gone. Eastward, the Cliff rises to about 100 feet in height, with constant deeply indented falls, continuing high until near Bawdsey sea-mark, where it declines towards Martello Towers W. and X. to about 20 feet. Between these Towers, at Boat House, or East End Point, the Cliff is only 8 or 10 feet high; the beach increasing to 60 yards in breadth, in two large 'fulls,' with fine shingle below, and a solid sandy foreshore.

Northward, the beach increases to two series, or four 'fulls,' and past Towers X., Y., and Z., there is a lofty beach, very similar to that at Kingsdown and Walmer, in Kent, from 100 yards to 200 yards in breadth, with ancient 'fulls' parallel to the present coast-line close up to the low land. This beach bears N.E. by N., and is nearly straight for a mile and a quarter. There are three sets of

'falls,' equal to six ridges of large beach; the largest cast up to the summit. An early sea-wall, grass-grown, a mile in length, is situate a long way back inland, between the shingle and the Towers; and the battery in front of Tower Y. is a long way inshore of the shingle. Between Towers Y. and Z., the back of the old beach is about 70 yards in advance of the old sea-wall. The old sea-beach is about 50 yards, and the modern shingle is about 100 yards in breadth. The lofty crest of this modern formation is very similar to that presented by Sandown Beach, in Kent, six years back, before it suffered so materially as it has done recently; and it is about 5 feet above the old sea-wall. Here, again, the

Fig. 8.



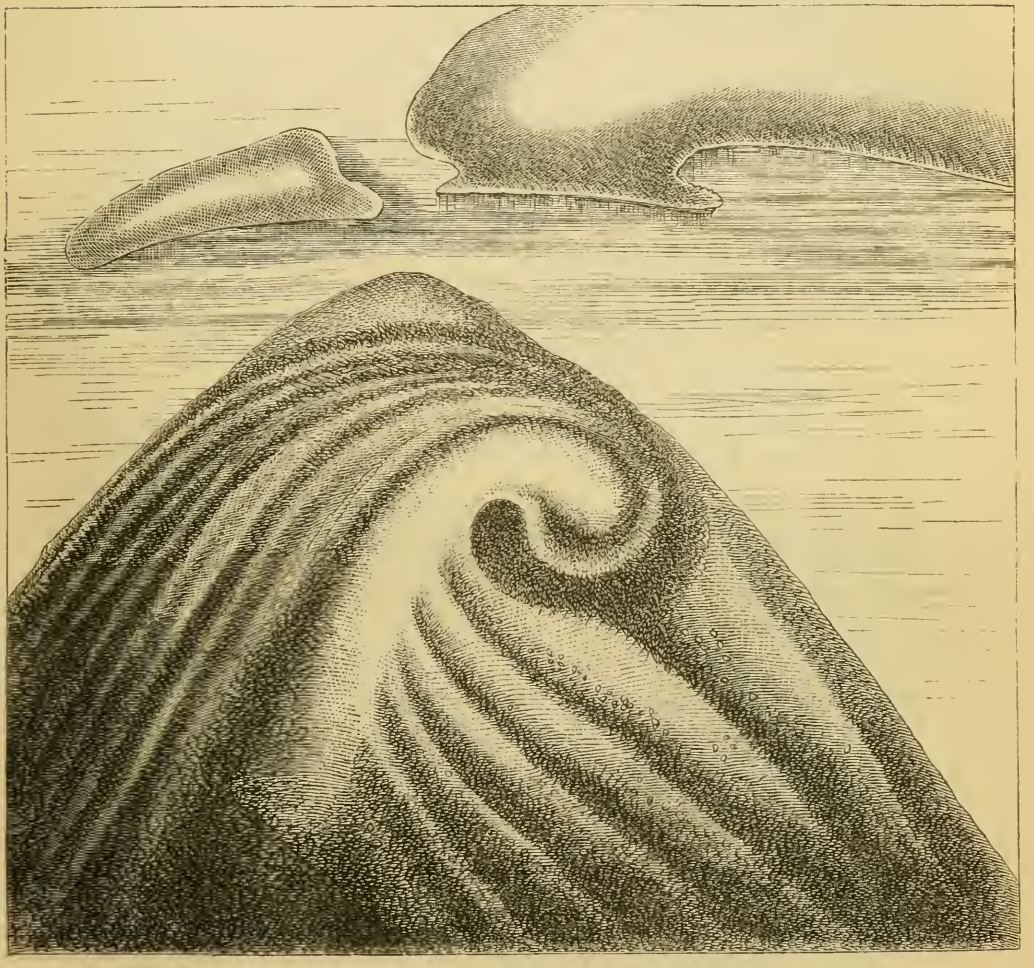
North Weir Point.—Sketch plan.

largest boulders are found on the crest, and, as is usually the case, the modern beach is the highest. Bawdsey Beach is the

overplus from Orford, formed in a bight favourable for its retention.

Northward, on to the outfall of the Rivers Ore and Alde, all is pure rolling beach, past Shingle Street—a collection of small Boatmen's Cabins on the beach. Here is a large horn of accumulated shingle, which, in its outline, becomes irregular near the outfall of the river. The largest pebbles are found cast on to the crest of the inner 'full,' between which and the outer modern

Fig. 9.



North Weir Point, looking S.W.

crest there is a deep gully, the site of the old entrance to the harbour, when at one period it was farther south, accounting for the local irregularity in the beach.

The 'North Sea Pilot' thus describes Orford Haven:—"The entrance is subject to frequent change, and there are persons now living whose memories go back to the time when it was $1\frac{1}{2}$ mile

westward of its present position; but wherever situated, its principal features remain the same.

"The extremity of the eastern beach is named the North Weir, or North Ear, below which are numerous detached banks of shingle termed the Haven Knolls, and through these the river maintains a channel, and generally a swatchway besides: 5 feet is the average depth over the bar at low water springs."

From this description, it would appear that the entrance was once near Tower Z., at the north end of Bawdsey Beach, and that the Haven Knolls formed portions of Orford Beach.

When this inspection was made, there was a main triangular bar of shingle across the entrance, and the shingle spits at the entrance were a long way out seaward into Hollesley Bay. North Weir Point, a huge mound of shingle, is the southern extremity of Orford Beach, and forms the north boundary to the entrance, from whence the mean bearing of the shore, looking south across the entrance, is S.W. 5° W., in the line of the triangular bar and mean shore line.

The sea slope is formed of fine shingle, very fluctuating, similar to Landguard, with an abrupt crest. North Weir Point is formed by a number of curved horns overlapping each other, with a deep hole at the nucleus, as in other similar formations. Without exception the largest pebbles are on the summits of the upper 'fulls,' and are found thrown over on to the back, or river slope.

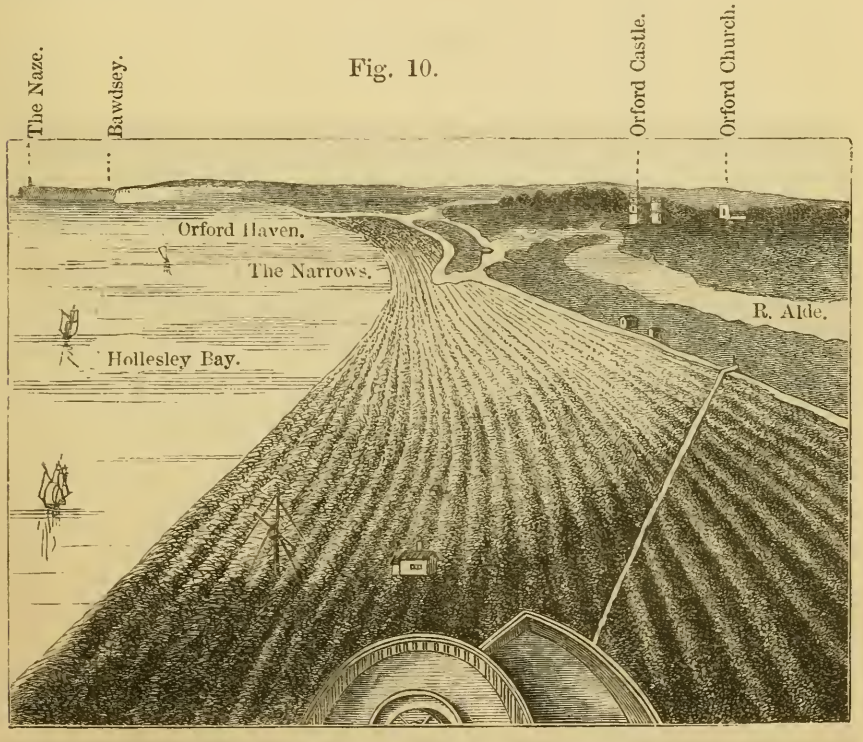
The curved horns, which formed the termination of the beach at various periods of its formation, may be traced all along the beach from North Weir Point to the Boat House, distinctly defining the sites of former outfalls, and the progressive march of the shingle mole in a S.W. direction. The overlappings of what have been the successive terminations of the beach, are traceable step by step, the hollows between the successive ridges becoming grass-grown. About a dozen main 'fulls' parallel to and enclosing the course of the River Ore, may be counted along the crest of the formation, which attains an altitude at the summit of 10 feet above high water spring tides. Ascending higher up the river, ooze is deposited on the land or river side of the beach with small saltings near neap range.

Orfordness.—This extraordinary mole of shingle is 10 miles in length, parallel to the shore, formed on the confluent channels of the Rivers Alde and Ore as its base. The general direction of Orford Beach to the south of the Ness is S.W., and northward, Alborough Beach bears N.N.E. Orfordness is formed of a series of curved concentric 'fulls,' sweeping round and forming a projecting point in advance of the general coast line, about 5 miles north of North Weir Point. The triangular projection thus

formed encloses salt marshes next the rivers. A remarkable and deep pool is found in the body of the beach between the High Light and the Marsh House, apparently the remains of a former outlet of these rivers.

Two views are given, taken from the summit of the High Light, which show the disposition of the shingle 'fulls,' and the manner in which the point has grown out, with the local variations and vicissitudes to which it has been subject. The first view (Fig. 10), is taken looking W. by S., in the direction of the main belts of modern shingle parallel to the present shore. Landward, these 'fulls' are 5 feet lower than those next the shore. Off the Marsh House, midway between the High Light and North Weir Point, and towards the 'Narrows,' there is a local twist, or change in direction, of every successive ridge of shingle. This has produced a series of hummocks east of Orford Water, opposite Orford Quay and Castle, having the appearance of horns, or bars, east of the old haven, precisely the position defined as the outfall in the Cotton maps of the time of Henry VIII.

Fig. 10.



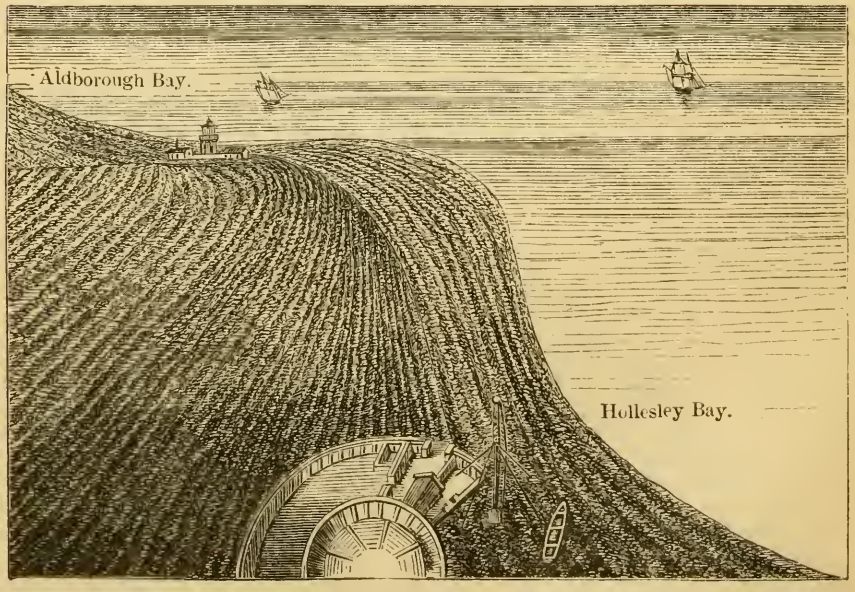
Orfordness, from the high Lighthouse to the Naze, looking S.W., showing a local twist in 'fulls,' E. of Orford Waters, like horns, or bars, E. of the Old Haven. The direction of the 'fulls,' along Hollesley Bay, is E. by N. to W. by S.

Very large pebbles are found on the summits of these ancient 'fulls,' which become lower in-shore, and which, curving round

towards the broad water opposite the Castle, denote the successive southern terminations of the beach at early periods; each successive horn shutting in a deep valley between it and the beach upon which it has formed; these terminations still remain and are distinctly traceable.

The second view (Fig. 11) is taken looking N.E. by E., towards the extreme projection of the Ness and the Low Light. It shows the relative positions of the ancient and modern 'fulls' of shingle; the former in a direction due east, and the latter changing to E.N.E. $4\frac{1}{2}^{\circ}$ E. Outside, formed between the two Lights, and constituting the boundary between Hollesley, and Aldborough Bay, there is a modern projection of the Ness, of a brighter, yellower appearance than the rest of the mass. This accumulation, which is the growth of the last twenty years, is entirely local, and has been made in a series of convex curves overlapping each other, and forming a point of from 200 yards to 300 yards in extent.

Fig. 11.



ORFORDNESS, from the high Lighthouse looking N.E. by E., showing the modern spit of 18 years' growth, between Aldborough Bay N., and Hollesley Bay S., 200 yards to 300 yards in breadth seaward, the direction of the ancient 'fulls' W. to E., and near the high light-tower, W. by S. to E. by N.

The general formation of Orfordness is like Dungeness, and like it, has deep water close up to the point; and again, similar to

Langley Point, the ancient 'falls' are intersected at an angle by modern formations. Very large flint boulders are found on the summit of the Ness behind the High Light. The local increase at the point has been accompanied, as in the former examples, by a corresponding decrease, viz. off the Low Light and towards Aldborough. In illustration of this, the present Low Light was formerly the High Light, and the old Low Light was situated E. by S. of it, some of the foundation piles of which were visible in the sea a few years since. The base of the tower and the connecting bridge have disappeared about four years. These remains extended to low-water mark. The present distance, from the High Light Tower, to high-water mark is 100 yards, and from the Low Light Tower 150 yards, and the old Low Light Tower was 300 yards east of the present Tower.[1]

A chart of the coast of Suffolk, from Orwell Haven to Gorleston, of the time of Henry VIII., showing the various forts and beacons, when so much attention was paid to the question of coast defences, shows distinctly that the mouth of Orford Haven was then opposite the Castle. A chart of the time of Elizabeth (Plate 2, Fig. 4), from Bawdsey to Thorpe, shows a considerable southern progression, and county maps of Suffolk, of 1723 and 1787, also show this continued increase: North Weir Point is now opposite Hollesley. It was, half a century back, more than a mile still farther south, so that in three centuries the shingle appears to have travelled south-westward 5 miles, giving an average annual leeward progression of 30 yards. This rate must have been even greater over certain periods, as for some years past, the outlet has been stationary, or rather it has receded northwards, and forced its way through a weak part of the beach, or possibly through a partial breach caused by the sea.

Thorpe Ness forms the northern boundary of Aldborough Bay. It appears to have grown out to the extent of from 30 yards to 40 yards during the last few years. This may be seen by comparing the old and modern shingle, the relative sites of the boat capstans, and a comparison of the present margin, and that shown on the Ordnance maps. North of Thorpe, the shore recedes; the yellow sandy cliff is grass-grown, 20 feet to 30 feet in height, bounded by a belt of shingle 100 yards broad, diminishing in quantity towards Sizewell. Here the shingle increases, forming a spit, which has grown out in twenty years from the earlier grass-grown portion, in extent about 85 yards, equal to an annual increase of

[1] The present distance to the High Light Tower is 95 yards, and to the Low Light Tower only 115 yards, where there has been a local decrease, equal to 10 yards per annum; and northward there is an evident recent increased waste of the shore.—J. B. R., 5th July, 1865.

$4\frac{1}{4}$ yards; half a dozen parallel belts of shingle and sand line Sizewell Bay.[1]

The enormous masses of sea-drifted material that fringe the shores just passed along, in parallel belts, for miles in extent, over many acres in breadth landward, at Landguard, Bawdsey, Orford, and Aldborough, to the present point, sufficiently attest the degradation of the N.E. shores for centuries past. All have one uniform leeward motion, and increase southward; and all are heaped up in parallel belts, representing the periods of time over which these changes have taken place.

Landguard Beach has an extreme length of—

	2 miles	by $\frac{3}{4}$ mile greatest breadth.
Felixton Beach . . .	3 miles.	
Bawdsey Beach . . .	5 „	„ by $\frac{1}{4}$ mile extreme width.
Orford Beach . . .	5 „	„ by $\frac{1}{4}$ ditto.
Orfordness Beach . .	2 „	„ by $\frac{3}{4}$ ditto.
Aldborough Beach . .	3 „	„ by $\frac{1}{4}$ ditto.

All are portions of one continuous belt of shingle, 20 miles in length, from Aldborough to Landguard Point, which may be regarded as its southern extremity, or Shingle End; as the formation of that name opposite Sandwich, in Kent, is the eastern termination of the great southern belt of shingle, reviewed in the Paper on the South Coast in 1852.

From Sizewell Cliff to Minsmere Cliff, the intervening marsh Minsmere Level has a frontage of $2\frac{1}{4}$ miles next the sea, fringed by a wide belt of low drifted sand-hillocks a furlong broad, then two series of shingle, old, and modern, south of the sluice at the new drainage outfall; the sand-hills are 120 yards in width, the beach is 30 yards in width, with a sand foreshore beyond; the beach and sand-hills decrease northward; the latter are cut into, presenting serrated edges as at Sandown, in Kent, and elsewhere, where the modern beach is retreating upon the base formed by the early sand 'dunes;' those near the sluice, are cut into, so as to present a section of the sand-hills with edges standing 8 feet to 10 feet above the beach, heaped against their face. North of the outfall to Minsmere Cliff, the level is defended by a sea-wall behind the sand-hills, which continue to be encroached on with a thin shingle 'full' driven against them; these sand-hills now lie behind the projection of Minsmere Cliff; but as the latter falls, there will be a corresponding waste of the sand-hills. Northward of the bottom, beyond the Coastguard station, the cliff falls to such an

[1] At Sizewell and Minsmere there has been a considerable decrease of shingle, and groynes have been erected at the latter place.—J. B. R., 6th July, 1865.

extent as to cut off the old path. At Dunwich Heath, masses of crag and bright yellow sand may be seen sliding down the face of the cliff, which is, here, about 100 feet in height, and is intersected all the way to Dunwich, with parallel fissures, the foot of the cliff being strewn with dark mould and heather, brought down upon the fall of the crag. Two 'falls' only of fine shingle skirt the base, on the broad sand foreshore; at one particular spot, south of Cliff House grounds, there is a deeply-indented honeycombed fall, about 20 yards on the face, and 10 yards deep.

Dunwich.—The intersection of the path along Cliff House frontage, constantly recurring, shows the progressive fall of the cliff, which here becomes literally an inclined plane of sliding sand. It is lower towards the ruins of the old church of All Saints, 62 yards distant from its edge: south of this church, a groyne of stakes, across the foreshore, is evidence of attempts made to arrest the decay. The foreshore is sandy, with a thin beach covering, and narrow, there being but 20 yards from half-tide level to the shingle, and 30 yards of fine shingle in two 'falls' at the base of the cliff, with deep water close in shore. The cliff is 50 feet in height, and consists of loam, crag, yellow sand, and marl; north of the church, near the signal-station, it declines suddenly into low marsh land as far as Southwold, which is bounded by a sandy bay, crowned by five beach 'falls.' For 4 miles in front of Dunwich Bay, the shore is 100 yards broad, consisting of 40 yards of old, grass-grown shingle next the marsh land, 100 yards of modern shingle, and 20 yards of sand foreshore to half-tide level. At one place, near the centre of the bay, the crest of the beach is piled to prevent the sea flowing over. The shingle increases in breadth and height south of Southwold piers.

The outfall of the River Blyth forms a small tidal harbour at Southwold, confined, or rather attempted to be confined, through the shingle, by two small wooden piers, in a S.E. direction. A large mass of shingle is heaped up at the back of the South Pier, 100 yards in width in advance of the angle of the Marsh Bank, in four parallel 'falls,' the inner ones of old standing. The crest of the beach is about 4 feet above the South Pier Head, which is half buried by the seaward 'full.' There is also a large accumulation of beach and sand within the entrance on the north side, formed of large boulder shingle, which passes the Pier Head and travels up the harbour. The North Pier has been recently extended to a similar distance as the South Pier, but the shingle from the northward is much in advance of it, and after passing the entrance, collects round the South Pier Head; in fact, under certain conditions of wind, the mouth of the harbour is entirely choked with shingle, and has been inacessible to shipping for weeks together. This was the case in 1859, so that persons could walk across the mouth

of the harbour; and during the spring of 1860, the beach was driven across the entrance up to high-water mark by easterly winds. During the winter of the same year, the ferryman and others used to walk across the entrance for two or three weeks continuously. When it was blocked up by N.E. and E. winds, as they described it, 'you might sit on the pier heads, the beach forming a convenient footstool below.' The land-water accumulating behind was frozen over, so that the harbour was literally sealed up within and without. These facts sufficiently indicate the decayed condition of this port, and the necessity for a much greater extension of the piers into deep water. On a recent occasion the 'Woodland Lass,' the largest trader frequenting the port, drawing 9 feet of water, waited a fortnight outside, and was subsequently another fortnight in getting from the Pier Head to Breydon Quay; showing that the harbour channel requires improvement as much inside, as the access demands it outside. A schooner of 60 tons burthen, lying at the quay on the 17th October, 1861, was stated to be of the maximum tonnage of vessels frequenting this harbour, about which so much was reported and said before the Tidal Harbours Commission in 1845.

A spit of shingle, seaward of the North Pier Head, overlaps it, and spits lie off both pier heads. The proposal at present entertained by the harbour authorities to carry out the North Pier 200 feet in five years, at the rate of 40 feet per annum, will, in all probability, barely keep pace with the attendant accumulation of shingle from the northward.

The early condition of the shore is plainly shown by a drawing (Plate 2, Fig. 6) in the Cotton Collection, A.D. 1509-47,—when two arms of the sea flowed over Westwood Marshes at the back of Dunwich, and over Reydon Marshes and Buss Creek at the back of Southwold, with a common outlet at Walberswyck Gatway, which appeared at that time to have a fathom and a half of water under favourable conditions. The estuary was, however, even then liable to be choked up. This took place as early as 1328, by N. and N.E. winds prevailing, and the pent-up waters burst a new outlet, 2 miles farther north, which must have been at the end of Buss Creek. This again was choked up at the commencement of the reign of Henry IV. A cut was then made which existed until 1464; its continuance was ascribed to the influence of a bank on the S.E. side; but when this sand-bank was washed away, the outfall was subject to constant oscillation. A fourth haven, called Hummerston's Cut, was dug near the last, but was frequently choked by a sand-bank lying N.E. of it, called Passeley Sands, on which many persons perished. In 1589 it was resolved to make a new cut, but the men of Dunwich, Walberswyck, and Southwold each preferred their towns as the site; and it was ultimately

forcibly opened by the men of the latter place; this proceeding caused a lawsuit of ten years' standing, ultimately referred, in 1600, to the Attorney-General Cook. This mouth, having no artificial protection, was constantly stopped, and was almost useless from 1614 to 1618. The Commissioners for the Harbour obtained their first Act in 1747, and the piers were commenced in 1749. Between 1805 and 1818, it appears the haven was dug out thirteen times, or once a year. Subsequent to 1829, the harbour was somewhat improved, by the removal of shoals, and appears to have gone for ten years without being blocked up. All this shows, that, however injurious may have been the wholesale embanking of the marshes on each side of the river, so much insisted on before the Tidal Harbour Commission of 1845, still, owing to other causes, the harbour has been in a worse state in early times than now, as may be gathered from what was said of it by Gardner, the old historian of Dunwich.

The present condition of the haven is not materially altered. It has from 8 feet to 10 feet water at high-water springs, and 4 feet to 5 feet at neaps; with a small rise of tide, viz. 8 feet at springs. Still the bay is unencumbered with shoals, and there is deep water close up to the shore; so that a further development of its resources may be hoped for.

Northward of the harbour the beach lies in a N.E. direction, from the new north pier head to the signal station at Southwold, and is 70 yards in breadth, from the sea-wall in front of the Town Marshes, the earlier 'fulls' being grass-grown.

The town of Southwold[1] stands on a terrace cliff of crag and clay, sloped and campsheeted in places, with two good 'fulls' of shingle at the base, gathering out in width, and increasing in number in the bay towards the piers, which they tend constantly to overlap. Northward of the small Southwold promontory, the head of Buss Creek is protected by a sea-wall, flanked by a broad belt of shingle: northward, a shingle-belt 30 yards wide is formed against the base of the cliff at Easton Bavent,[2] which contests with Lowestoft, the honour of being the "extensio promontarium" of the Romans, and if so, a loss of from 2 miles to 3 miles must have

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[1] This place suffered much during the winter gale of 1862. Large portions of the cliff were then washed down, and this was no doubt induced by the constant degradation of the cliff south of Covehithe Ness. Three lofty groynes have been erected—one finished and two partially so. They are not of a character to arrest the waste. The pier on the north side of the harbour has also been lengthened 60 feet. The entrance was, however, blocked up for three tides in the first week of July, 1865, and a vessel of 120 tons was lying ashore off the entrance on the 10th of that month.—J. B. R.

[2] The edge of the cliff is now 14 yards from the east angle of the farm buildings at Easton Bavent.—J. B. R., 10th July, 1865.

occurred since that period, which would account for the degradation at Dunwich, produced by this increased exposure. The 'North Sea Pilot,' says—

> "The sea has made great ravages here, for, according to tradition, the easternmost point of England and the city of Easton Bavent formerly occupied a site abreast, which is now 2 miles from the land."

Stretching 2 miles northward of the small sandy cliff at Covehithe is Covehithe Ness, enclosing Benacre Broad, formed of sea-sand, now covered with gorze and fine turf over the entire surface. Three distinct ancient mounds of shingle may be traced. A walking cane pushed through the heather and rich mossy turf grates immediately upon the beach. Seaward there is a considerable area of sand-hills, and then a high mole of modern shingle, the sand-hills being separated from the ancient and modern shingle belts by two broad and deep parallel valleys. South of Benacre sluice, the following are the widths :—

200	yards	ancient shingle in several parallel belts;
150	,,	sand-hills 30 feet high;
30	,,	upper 'fulls' of modern shingle, 10 feet above high water;
60	,,	shingle and sand foreshore to half-tide range,

or, 440 yards in all south of Kessingland.

At the north end of the Ness, as is usual with these formations, the sand-hills increase in height on the windward side, and meet the low cliff at Sea Row; the slope of which, towards Kessingland, is about 30 feet in height, covered with sand-drift and long grass, with a broad belt of shingle and sand at the base. The largest pebbles are here collected in quantities, and stacked at the foot of the cliff for building purposes.

At Pakefield the cliff is about 50 feet high. The yellow sand mixed with clay crops out at the base, and a deep chine exists at the Lighthouse.[1] The foreshore, of shingle and fine sand, is 70 yards broad. The cliff gradually declines from Pakefield and Kirkley to Lowestoft, with a broad belt of sandy foreshore stretching out towards the Ness.

No attempt will be made to describe the well-known character-

[1] This light is now discontinued, and a temporary light exhibited in lieu thereof at Kessingland, to mark the southern extension of the Newcome Sand; new lights are also being erected at Corton as leading lights for Corton Gatway. A light is also being erected to define the seaward projection of Lowestoft Ness. These changes have been brought about by the southern movement of the sands.—J. B. R., July, 1865.

istics of Lowestoft harbour, beyond reverting to the fact, that its origin and its maintenance are equally artificial, for it was formed by means of a connecting cut and a lock into Lake Lothing, and its depth is kept up by constant dredging. Still, it is no ordinary feat to execute and maintain, on such a coast, a port possessing a depth of 12 feet at low water, 18 feet to 20 feet at high water of spring tides, and 10 feet at any period of tide, and into which have entered not only vessels of 400 tons burthen, but even a steamer of 700 tons burthen. The fleets of vessels that may be seen at the fish-curing houses, the tugs passing backwards and forwards with their fishing convoys; others with their fleets of mud-hopper barges, are all indicative of the enterprise called into existence by the introduction of modern capital and appliances.

The position of Lowestoft as a harbour is in some respects advantageous. Like Yarmouth, it has its outlying sands and intervening roads, though much more contracted in character, and it lies to the southward of the projecting Lowestoft Ness, — the roadstead being almost shut in from the projection of Covehithe Ness south, to Lowestoft Ness north, by the outlying Barnard, Newcome, and Holme Sands, for 7 miles in length, forming Lowestoft South Roads. Northward of the Ness, Lowestoft North Roads, of a similar length, are formed by the Holm and Corton Sands, joining Yarmouth Roads, which are again formed by the Scroby Sands. These combined roadsteads, 20 miles in extent, are well known to mariners navigating these dangerous shores, whose safety depends on a constant observance of the treacherous material forming a bulwark against the storm.

The recent change of the Stanford Floating Light, which was moored abreast of Lowestoft, to mark the north entrance of Stanford Channel, which has a north and south direction between the Newcome and Holme Sands, is sufficiently indicative of the shifting character of these sands. The necessity of moving this light northward to the Corton Gatway, arose from the Holm Sand outside the Stanford Channel tailing out $1\frac{1}{4}$ mile to the south. In fact the outlying sands grow out southward, corresponding with the movement of the littoral deposits, denoted by the tailing out of their southern extremities, the wasting away of their northern projections, and by the closing up, in some instances, of intervening and well-known gatways, or swatchways, used for navigation. Pakefield Gatway, south of Newcome Sand, has shifted 2 miles south, within the recollection of pilots of thirty years' standing.

At Lowestoft Ness, the foreshore is mainly sand. The entire upper surface on the south side, in the neighbourhood of the open timber Low Light Tower, is covered with white driven sand, of a flocculent character, shifting rapidly in every direction. Northward, below the sloping cliff on which the old town stands, are 'Denes'

grass-grown, hillocks of drifted sand, covered with gorze bounding them next the sea. An ancient 'full' of sand and shingle, parallel to the cliff, is traceable within the angular accretion and projection of the Ness. At the point of the Ness commences a shingle 'full' of pebbles, the largest being on the crest. These are collected for building and road purposes, and measure 5 ins. × 3 ins. × 2 ins. Round the north-east elbow two 'fulls' of fine shingle make their appearance, and two early 'fulls' inside: then pure sand; the shingle reappearing southward at Pakefield, as before noticed. At the Point, the foreshore of sand and shingle is steep, and about 30 yards broad to low water; the navigable channel lying close in between the Ness and outlying Newcome and Holme Sands. There is deep water, 6 fathoms, close to the Ness, as is the characteristic of all these formations, so that it is the practice to throw whiting-lines from the shore, by which good fishing may be obtained. Across the 'Denes,' on the north side, opposite the boat-house, the following is a section of this remarkable spit:—

25 yards, sand and shingle foreshore, 7 to 1;
6 „ 'full' of recent shingle at high water;
30 „ sand and large blue pebbles up to grass-grown
— sand 'Denes.'
61 yards of shore seaward of 'Denes.'

These 'Denes' are flanked landward by a deep valley lying between them and another line of 'Denes' parallel to the cliff, at an angle to the present shore line, the whole being backed by yellow sand-cliffs gently sloped and covered with gorze, heather, moss, and ferns. Northward the shingle is less defined. From the sand hills seaward there is a long foreshore, to a regular slope of sand-and pebbles 100 yards in breadth, down to low water. The shingle 'fulls' are local at the point of the Ness.

There have been considerable fluctuations in the Point of the Ness, during the last ten years, the general result being, a wasting of the shore on the weather or N.E. side, accompanied by a corresponding local increase on the leeward or S.W. side, producing a southern movement of the Point.

At Corton, the cliffs lose the protecting influence of the Ness, and falls recommence, but there is a large amount of drift-sand at their base. The village of Corton is now close to the cliff: roads are intersected and others stopped up, that are shown entire on the Ordnance Survey, and some of the large substantial farm-buildings close to the cliff have been pulled down in anticipation of its continued fall.[1] The cliff continues to fall and retreat

[1] This waste continues, and some temporary expedients have recently been adopted for the protection of the base of the cliff.—J. B. R., July, 1865.

close up to the commencement of Yarmouth South Pier at Gorleston, necessitating the advance of the angular curved outworks at the root of the pier, to counteract the tendency the Yarmouth waters always have had to run south under the cliff, which is increased by the sea eating into the angle outside, south-west of the South Pier.

The sands at Yarmouth, like those at Lowestoft, have been comparatively stationary for the last quarter of a century. They have a per centage of flint boulders, a large number of which have been used for making roads within an esplanade wall, in front of the new portion of the town, north of the Victoria Jetty. The extensive area of the 'Denes,'—used by the fishermen for drying their nets, and on which is the race-course, lying between the harbour channel and the sea, with a long sandy foreshore, and the entire site of the old town and of the Abbey Church of St. Nicholas, with its extensive burial-grounds—is all one vast deposit of sea-driven sand, formed across the outfalls of the Rivers Waveney and Yare: the joint outlets of these rivers run into the head of a large mere — Breydon Water,— the outlet of which, being joined by the River Bure, forms the harbour channel. This is constantly forced to the southward, by the accumulation of littoral sands from the north, and the struggle has always been to confine the outlet waters at the turn called the Brush, and to direct them out to sea, at right angles to the shore. When it is considered that this area of sand, 5 miles in length from Caistor Point to the piers, and half a mile wide, equal to 1,600 acres, has been formed across what was a large estuary during the occupation of the country by the Romans, some idea may be formed of the enormous accumulations that have taken place. (Plate 2, Fig. 5.) At Caistor on the north, and Burgh on the south, were stations: the remains of the last are very similar in character as well as position to those of Richborough in Kent, and both have been left by the sea under like conditions. The old town of Yarmouth was formerly on an island, with two outfall channels—one at Caistor, the other at Gorleston. The first was eventually abandoned, and the town consequently decreased on the north side, and extended southward. The Gorleston Channel, which was formerly subject to continual fluctuations, was, after much labour, rendered permanent; but this was not effected without the aid of Engineers from the low countries. Probably the 'Brush' derived its name from the brushwood used by the Dutch in their operations. In the reign of Edward the Confessor the two outfalls were, one between Yarmouth and Caistor, called 'Grub's Haven' and sometimes 'Cockle Water,' and the other 3 miles to 4 miles south of Yarmouth towards Corton, and there were six successive havens before the formation of the

present outlet in 1559. This harbour is now the most important on the coast, with 10 feet at low water, and employs five hundred vessels in the foreign and coasting trades. It is a great fishing rendezvous, and has a considerable inland trade, with prosperous ship-building yards. The tendency has always been for the north bar, north-east of the North Pier, to travel south across the entrance.[1]

At Winterton, a broad belt of sand extends at half tide, outside the high water 'fulls' of sand and pebbles; the foreshore being 150 yards in breadth, from half-tide range, to the base of the outer range of sand hillocks. Past Winterton, Somerton, and Horsey, an extensive range of sand hillocks forms a barrier to the marshes. From Winterton to the Ness Point there is an outer and inner range; the land range low, that next the sea from 50 feet to 60 feet high, tossed into the wildest forms, with deep basins, and beach in the hollows. There is a sandy foreshore, 150 yards in breadth, with a shingle 'full' close up to the foot of the sand-hills. At the extreme north-east spit, of rounded sand foreshore, off the signal station east of Warren House, the sand-hills diminish in height, and shingle is driven through the interstices occurring in their outcrop where reduced by the sea. Northward, the 'full' of large pebbles increases in volume; the single range of sand-hills from the Ness Point to Waxham is of great height, about 70 feet, but nearly breached in places, with hurdle-work across the partial breaches, and small shingle driven right up the sea slopes.

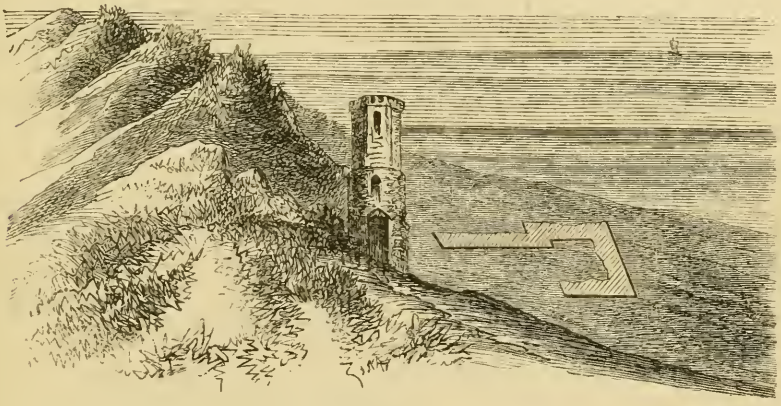
The old tower of Eccles Church (Figs. 12 and 13) has been immortalized by Lyell. The sea slopes of the sand-hills are now behind the Round West Tower, which is washed by the sea at high water. The foot of the sand-slope was, in October 1861, 17 yards in advance, seaward, of the Tower before the foundations of the nave were seen; then 8 yards of the north wall appeared through the sand, the south foundation wall being buried in driven sand; the chancel foundations walls, 13 yards long by 8 yards broad, were completely uncovered. The old Tower is filled, at

[1] There has been a great increase in the littoral sands immediately abreast of the frontage of the town, but north at Caistor and south at Gorleston the waste has correspondingly increased, and the bar of the harbour has become more troublesome, with a loss of 18 inches of water at the entrance. The North Sand overlaps the entrance, and vessels drawing 16 feet of water are lightened in the Roads. A large American barque in the Roads, timber laden, was discharging into lighters on the 11th July, 1865.

The continued increase of the North Sand at the entrance to Yarmouth, and of the sands in front of the town and the new esplanade walls, which four years back stood considerably out of the sands, but are now buried therein, is attributable to the constant and continued degradation of the shore north-west of Caistor. A groyne at the last-named place is much wanted. The harbour of Yarmouth is now rapidly lapsing to the condition it was in half a century back, when 10 feet, and not 15 feet, was the maximum depth over the bar, and which is now reduced to 13 feet 6 inches.—J. B. R., July, 1865.

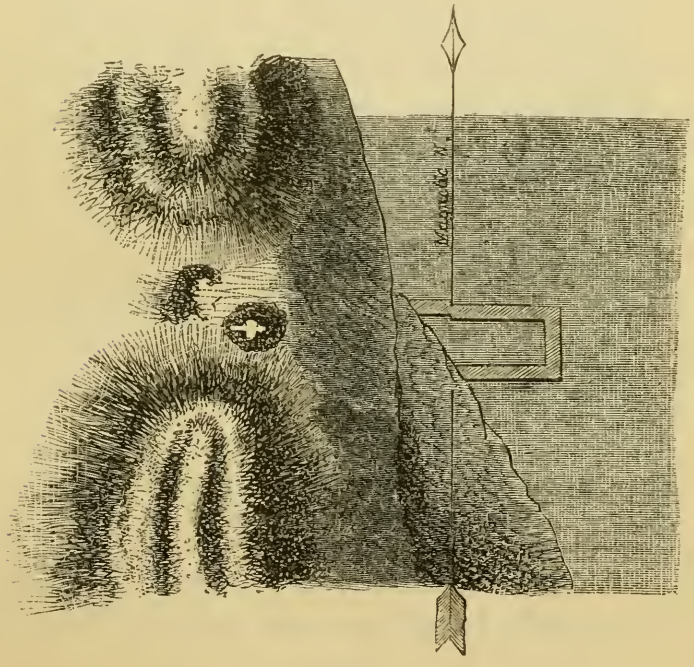
the base, with driven sand, which has found an entrance by the south door. The foundations of old houses may be seen cropping

Fig. 12.



Eccles.

Fig. 13.



Eccles.

out through the foreshore at low ebbs to the eastward of the Church. The summit of the Church Tower is level with the top of the sand-hills.[1]

[1] The 'Marrams,' west of Eccles Church, have receded about 15 yards in the last three years, and in the neighbourhood of Palling; the shore suffering much during the gales and high tides of the last two years.—J. B. R., July, 1865.

Three quarters of a mile north-west of Eccles the 'Marrams,' which have been traced in almost an uninterrupted belt of 16 miles north of Yarmouth, terminate, the only break in their continuity being at Scratby Cliff. At Happisburgh the clay crops out, in low cliffs about 30 feet high. Past the Lighthouses, and the Preventive Station, they fall a good deal, and masses are to be seen projecting through the thin sand-covering of the foreshore. The Church, with a tower 127 feet in height, on a knoll, a short distance from the Cliff and 40 feet above it, presents, in its noble proportions and decorations, evidence alone of the enormous waste of the coast. It appears when the last portion of the hotel was built in 1803, it was a quarter of a mile, or 440 yards from the edge of the Cliff. In October 1861, it was 310 yards distant, or 130 yards less, in fifty-eight years, equal to an annual loss of $2\frac{1}{4}$ yards.[1] The 'North Sea Pilot' gives a higher result, viz. 2·83 yards per annum; and it is surmised that, should the present waste continue, this noble church and the village will have been swept into the sea by the middle of the ensuing century. This portion of the coast is remarkable for the number of its churches, leading to the inference that it was once more inland and more densely populated. From the High Light Tower, and from the hotel windows, no less than thirty-eight can be counted. The Lighthouses are half a mile south-east of the village, and are leading lights for Hasborough Gat, leading clear of all the outlying sands lying off Winterton and Yarmouth, also denoted by the Newarp Floating Light.

N. N. W. of Happisburgh, the cliffs, 50 feet to 60 feet high, fall much. They are of light yellow sand above, and of dark clay below. The waste is shown by the disappearance of the 'Summer House' north of the church, and the road thence to Ostend, both included in the Ordnance Map. This gives a decrease of $\frac{1}{2}$ a furlong, or from 3 yards to 4 yards per annum. The whole range of cliff here presents one continued series of slips. The earth fences enclosing large fields are intersected, leaving a series of small hillocks on the edge of the cliff. The loss at Walcot on the frontage of one farm is known to have been 40 yards in breadth in the last twenty years. The meeting of the roads north west of Ostend, a cottage,

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[1] This distance is now 305 yards, but the waste of the cliff at the Preventive Station is greater, being estimated by the Coast-guard officers as equal to 10 yards in the past three years. The cliff at Happisburgh is only 20 feet to 30 feet, and looking at the character of the land and buildings, the question arises, whether it would not pay to convert it into a slope, and properly pave and drain it; agricultural operations, stripping the clay from settled portions, from the way in which they are conducted, must often hasten the decay.—J. B. R., July, 1865.

and a meeting of roads at Walcot Gap, shown in the Ordnance sheets, are all gone.[1]

Towards Mundesley the yellow sand-cliffs, capped with 'crag,' rise to a height of 100 feet. They are of undulating outline, formed by the outcrop of the downs and valleys of the tertiary strata. In places, from the upper stratum of crag are to be seen sliding down the cliff face, masses of water-worn flints, so that the large boulders found on the shore are not modern, but diluvial shingle nearly 'in situ,' only at a lower level of from 50 feet to 100 feet. Here, the cliff face, in places is a complete avalanche of sand, loam, and gravel. S. E. of the small watering-place at Mundesley, the cliffs decline to 40 feet, or 50 feet, and the frontage of this bathing-place has been protected, by walling the face of the cliff.[2]

Fig. 14.

Coast S.E. of Mundesley.

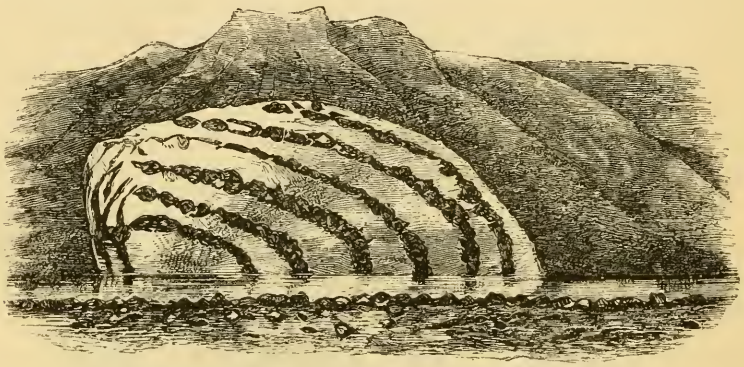
The large angular bastion at the south end at the Flag Staff had recently fallen in October 1861, and three years prior, the lower

[1] The characteristic of the foreshore from Happisburgh to Mundesley is the great height of the sand, in two rounded 'fulls,' with a deep runlet between. The sand drifts against the cliff, and thus forms a natural protection. Six teams were actively employed in the afternoon of the 14th July, 1865, in removing this sand. —J. B. R.

[2] These walls are now a mass of ruins along the entire frontage; they appear, however, to have been a mere skin of flint-work, with few counterforts or bonds into the cliff. Here three or four teams were actively employed in removing the sand and the large flints which lie in the deep rivulet between the spring and neap sand 'fulls.'—J. B. R., July, 1865.

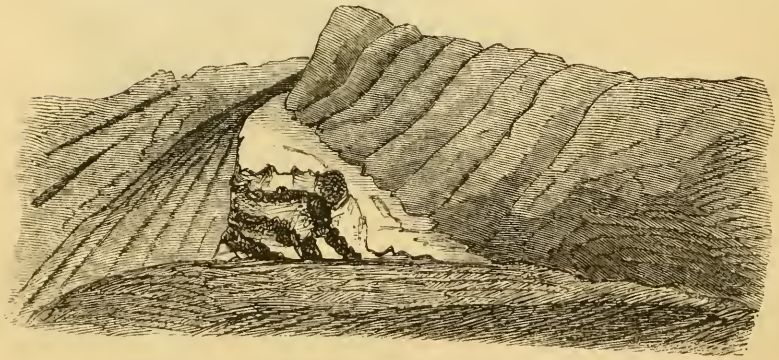
walls were also breached. The upper wall suffered in the same way during the winter of 1860. 'All Saints' church on the North Cliff, in its fallen tower, large nave partially enclosed, and roofless aisle, bears striking testimony to the decay around. The S. E. angle of this church was, in October 1861, between 70 yards and 80 yards from the edge of the cliff. On the Ordnance Map, this distance is $\frac{1}{2}$ a furlong, equal to a mean loss of $4\frac{3}{4}$ yards per annum. Northward of Mundesley, the farmers abandon ploughing close to the edge of the cliff, and have two fence banks, one next the edge, and the other connecting the heads of the chines; the intervening crescent-shaped belts between the slips forming rough grass enclosures.

Fig. 15.



Mundesley to Cromer. Isolated Chalk Peak.—Front View.

Fig. 16.



Mundesley to Cromer. Isolated Chalk Peak, from the S.

A mile and a quarter north of Mundesley, the chalk crops out, in a rounded boll very much contorted, the veins of flint being at a considerable angle. Shingle and sand are heaped up against its base, and it is capped by a lofty yellow sand-cliff. Two sketches are given (Figs. 15 and 16), the first looking full on, and the second northward of this exceptional stratification. This outcrop presents similar appearances at the present time, but has become

much discoloured on the face, from the constant slipping of sand from above; similar shoots of the cliff have taken place E. and W. of it. A similar outcrop of the chalk takes place two miles north of Mundesley. Northward the cliffs rise to 120 feet in height, of bright-yellow sand, very much contorted, with deep grass-grown chines. A ferruginous patch of highly contorted sand, and another peculiar isolated outcrop of the chalk, are met with. Between these two chalk points, the sand strata are twisted into the wildest conceivable forms, and avalanches of sand and clay occur. There is a steep sandy shore, with broad belts of gently declining sand to low water. Between the high water 'fulls' of sand, and the foreshore belt, there is a deposit of enormous flint boulders from the cliffs. These flints, 18 inches long and 6 inches in diameter, much beyond the ordinary size of modern littoral shingle, are, as before observed, diluvial pebbles, nearly 'in situ,' but dropped down some 100 feet by the wasting of the cliff. Here the chalk commences to crop out through the foreshore. S. E. of Trimingham enormous masses of sand, 200 feet in extent on the slope, with two or three flint seams embedded near the top, may be seen. Some of these slips varying in extent from 5 acres each to 10 acres each, form an undercliff 70 feet below the present edge of the cliff.[1]

Cromer has suffered much from the encroachments of the sea. It stands on the N.E. salient point of the county, and is open northward to the island of Spitzbergen. The present lighthouse stands at a height of 250 feet above high water, on the S.W. spur of the star-shaped cluster of downs, which have been severed by the continued inroads of the sea; and although the ground rises rapidly S.E. to the lighthouse, and also northward, the cliffs fronting the town are only from 30 feet to 40 feet high. The old lighthouse, erected in 1719, and abandoned in 1833, and formerly called 'Foulness,' is now only 5 yards from the edge of the cliff.[2] In front there is a great 'shoot,' or fall, with an undercliff of sand, loam, and gravel. The shore, not inaptly termed 'Foulness,' is bounded by chalk reefs beyond low water, as may be seen distinctly from the cliffs all along the coast. They are thus spoken of in the 'North Sea Pilot:'—

> "Foulness Rocks. The bottom in front of Cromer lighthouse "is an extension of a bed of chalk underlying the mud "cliffs; it is very uneven, and causes a high sea in "gales."

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[1] Here was picked up a large water-worn pebble of *granite*. The dark-blue clay forming the base of these cliffs, as may be seen in the split masses from the shoots, is full of water-worn chalk, pebbles, and flints. A mass of water-worn débris, when washed out of the clay, and again set rolling, would appear to be modern, and not diluvial.

[2] Present distance, 4 yards.—J. B. R., July, 1865.

The cliffs in this neighbourhood have, not very aptly, been termed 'Mud Cliffs,' for they are mainly of a bright sand, with immense deposits of water-worn flints in the upper seams of drift. Such a term would be more applicable to the Naze and Walton cliffs, where the London clay crops out in more defined masses. The position of the town is sufficiently indicative of the constant encroachments of the sea. Lying in a 'bottom,' the low cliff has only made a stand through artificial defences, which now form a point in advance of the cliff on either side. So large a church, so close to the cliff, without historical evidence, would be almost sufficient proof of waste. Its ruined aisle and chancel speak forcibly of the curtailment of the town. This place was anciently called Shipden, and as the 'North Sea Pilot' says, was,—

> "of considerable extent and importance, but half of the "town, including one of its churches, has been swept away "by the sea."

Groynes are run across the shore in front of the town, three being eastward of the landing-jetty.[1] There are several fissures in the sea-walls; and northward of the town, the sand-cliffs fall to a considerable extent. The footpath northward is cut off, and the slips come close up to the coast road, which is marked some distance back in the Ordnance Sheets; nor do the 'Marram' hills, therein defined, now exist. The cliffs, which are 150 feet high, are composed of yellow sand above, much contorted, and blue clay below, the upper stratum containing a large mass of gravel. The general line of cliff east and west of Cromer, now bisects the town, midway between the sea-wall and the church, showing that the sea-side portion of the town is an artificially supported point. Westward, another isolated out-cropping peak of chalk occurs through the sand-cliffs, and west of that peak, one slip forms an inclined plane of sand, at an angle of 45°, from near the edge of the cliff to the foreshore. Advancing westward, masses of cliff, which have slipped bodily, are met with, resting half way down, and covered with herbage.

Between Runton and Beeston, the chalk, in places, forms nearly the entire height of the cliff; in other places the sand crops out, mixed with the chalk which readily falls. Beeston Hill is 50 feet above the cliff, or 250 feet in all, and commands an extensive sea-board view. The foot of this hill is now close to the edge of the Cliff. At some distance from it, a similar hummock to the westward (shown entire on the Ordnance Survey), is now cut in two, displaying contorted laminæ of sand, and alternations of sand and

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[1] Additional groynes have recently been erected with more judgment than at Southwold, and have caused a large accumulation of sand and foreshore shingle.—J. B. R., July, 1865.

flints. The diminution here thus appears to amount to from $\frac{1}{4}$ to $\frac{1}{3}$ of a furlong in twenty-three years, from 1838, the date of the Ordnance Survey, or an annual loss of from 2 to 3 yards.[1]

Weybourn Beach commences, and now lines the shore, in a direction N.W. by W., in a continuous belt of 10 miles; assuming consecutively the name of Salthouse, Cley, and Blakeney Beaches, as it shuts in the 'saltings' (through which flow the harbours of those names), and terminating at the mouth of the last.

West of Cromer, the general southern leeward motion of the shingle, which has hitherto been traced along the coasts of Essex, Suffolk, and Norfolk, is now clearly reversed; and a local movement is found to the westward, due to the trend of the coast towards the Wash.[2]

Blakeney is at the best a mere tidal creek, through saltings enclosed by an outer natural barrier, formed parallel to the coast. The harbour is constantly deteriorating by deposit, hastened by the progressive enclosures for agricultural purposes. The great, comparative, rise of tide (15 feet), however, on this part of the coast, renders it an important local port, and it is available at the quay, for vessels of 200 tons burthen, and, in the harbour, of 300 tons burthen. Sixty tons appears to be the maximum tonnage for Cley, which is not available at neaps. On the 26th October, 1861, one hundred and twenty-four vessels were in the offing east of the harbours. The lofty tower of the church (104 feet high on the chalk downs), and which also has a curious open stone beacon lantern tower, is used by the pilots, some of whom aver that the movement of the harbour's mouth has been 500 yards within their recollection. The deep creeks which intersect the Moston, and Stiffkey marshes west of Blakeney, with the innumerable feeders running into them, well illustrate the conservative action of tidal agency alone, in preserving deep-water channels.

Between Blakeney and Wells, and thence westward to Brancaster, near the entrance to the Wash, a range of 'Marram' sandhills forms an outer barrier at high water, parallel to the high land, enclosing tidal estuaries of considerable area, the low-water channels from which have formed harbours along this part of the coast from the earliest historic periods. The Morston and Stiffkey 'Marrams,' between Blakeney and Wells, are one mile within the

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[1] The shore-works of defence off Beeston Church, commenced October, 1861, are now a mass of ruins. At Sherringham, flint and concrete walls, slopes, and groynes have recently been erected for the defence of the frontage of this large fishing-village.—J. B. R., July, 1865.

[2] The Weybourn beach has decreased of late years, and the sea was over the Salthouse and Cley levels two years back; the breaches, some of which cut clean down to the base of the wall, still remain.—J. B. R., 14th July, 1865.

Marram hills, which form the horn around the entrance to Blakeney Harbour, and west of Wells are 'Marrams,' which are a similar distance out, to those of Blakeney.

The sands rise in height towards the outfall of Wells harbour; shingle, mixed with sand, reappearing, thrown up from the north-east, in a crescent form against Wells 'Meals;'—the base on which it forms, tailing round into the trumpet-mouth between Wells and Holkham 'Meals' at high water, called 'Wells Beach.' From this point it is, at low-water springs, 2 miles over the sands to the open sea at the harbour mouth, and nearly a similar distance up to Wells Quay.

Holkham 'Meals,' $\frac{3}{4}$ of a mile in length, in a crescent shape, from the spur at the Life-boat House on the west side of the harbour to Holkham Gap, enclose the sites of the West Fleet and Holkham salt marshes, which at one time formed the west 'lung' of the harbour, as the east is formed by the Lodge and Wells salt marshes. A straight sea wall, a mile in length from the west end of Wells quay to the east spur of Holkham, now encloses the western saltings, and the harbour channel has been straightened abreast of this work. The sea was over this enclosure two years back, when much damage was done elsewhere. An immense quantity of light flocculent sand is brought up this channel to the bend at the quay, and is deposited in a north and south direction, in spits overlapping each other. The low-water channel, below the quay, was, in October, 1861, choked by spits of sand lying transversely. At a drainage outfall, through the new wall $\frac{3}{4}$ of a mile down the channel, where the two arms of the low-water channel formerly separated, the channel took a sudden twist, or bend, to the eastward. This was said to have been projected 30 yards in the previous twelve months. The sand appeared also to be collecting on the face of the new wall, on the site of the space formerly situate between the two old channels. The immediate effect of this wall has been to increase the range of tide at the quay, and there is from 18 feet to 20 feet of water at the harbour entrance at H. W. springs, sometimes increased, with N.E. winds, to a depth of 25 feet. What is likely to be the ultimate result to the harbour will not be conjectured on this occasion.[1] The west channel at the outfall is the main one; that on the east is closing up. Holkham 'Meals' attain an altitude of 40 feet at the 'High Cape,' the most projecting hillock on the convex side of the curve. The sand is blown over the surface of the 'West Sands' at low water, with N.E.

[1] The present state of the harbour is reported to be good, and shingle has formed to a slope along the seaward face of the new wall.—J. B. R., 15th July, 1865.

winds, and attains a considerable height below the 'High Cape,' with an increasing high-water belt of shingle.

The tract of shore in front of Burnham Overy, Burnham Deepdale, and Brancaster, is of the wildest character; the 'meals' enclosing a tract of saltings, intersected by the creeks first named, and their tributaries. The saltings, only covered at extreme floods, in extent, 5 miles by 1 mile, or about 3,000 acres, are of irregular width; as the 'meals' enclosing Norton Creek are a mile in advance of those enclosing Brancaster Creek, where separated by the common low-water outfall channel, below Burnham Deepdale. Over the Ness, thus formed behind the 'meals,' the largest shingle is driven in spits, through chines. Behind the sand 'meals,' the Ness is, in one place, 1½ mile in depth, from Scott Head to Norton Street. One great N. and S. spit of shingle, lying transversely to the general shore line, appears to define the range of wave behind the 'meals' from Burnham Creek. Another long spit of shingle stretches across the Ness N. by S. towards Brancaster Windmills, driven up from the eastward from Burnham Creek. In the same way, opposite Burnham Deepdale, shingle is found on both sides, seaward and landward of the 'meals.' Between the outfalls of Burnham, and of Brancaster there are, seaward, two well-defined shingle fulls, and a belt, 70 yards in breadth, of sand foreshore, which, during gales from E.N.E., to which it is peculiarly exposed, is strewn with flints. Lumps of chalk may be seen mixed with the flints, many of the latter, with their chalk matrix still adhering to them, showing the proximity of the source of supply. Here the 'meals' attain an extraordinary elevation; with the crater-like cups, or basins, peculiar to the largest sand-hills, invariably filled with the largest shingle; and the hillocks are here intersected by ravine-like depressions, forming sandy chines and peaks.

'Scott Head,' or as it is termed by the 'North Sea Pilot,' 'Scald Head,' is from 70 feet to 80 feet in height. From its summit, the seaboard eastward to Weybourn, and westward to Hunstanton, may be seen. The largest crater-like depression in this sand-hill is 100 yards long by 60 yards wide, and is 40 feet deep from the summit. Into this receptacle large shingle has been tossed in two 'fulls,' entirely above the ordinary shore shingle, at an elevation of about 30 feet above high water: a striking example of the great power of the sea. As a similar example, among numerous others, may be quoted, the second sand-hill, north of Battery No. 2, and immediately east of Sandwich, in Kent, where precisely the same phenomena may be observed.

Brancaster possesses great natural advantages; it has an outer road 4 miles long, and 1 mile wide, with a stiff clay bottom, and a depth at low water of from 3 fathoms to 3½ fathoms, and a rise of

from 19 feet to 20 feet at spring tides, and of 11 feet at neap tides. The low-water creek, a mile and a half in length W. of Scott Head, runs through the sand foreshore, in a N. by E. and S. by W. direction, and has 9 feet of water at Brancaster Staith. Trade has, however, entirely left the place. On the east side of the harbour there is a small high-water ness of shingle, formed around the 'meals,' tailing inward: when this spit is rounded, there is a considerable recession in the shore (Brancaster Bay), where, even with a stiff N.E. breeze, the sea soon becomes comparatively smooth.

At Hunstanton, or St. Edmund's Point, there crops out, with a gentle rise from the E., an exceptional stratification of red and white chalk, a stratum of from 15 feet to 20 feet of loose rubbly white chalk, resting upon the red chalk, which is 4 feet above the sand and shingle, and which breaks off in nodules. There is very little shingle round the headland; the chalk falling in large slab-like masses. The red chalk appears to wear away the more rapidly, or is more exposed, and leaves the white in projecting shelves, these subsequently fall in large masses, strewing the shore. The edge of the cliff is at present 10 feet from the garden wall of the lighthouse, erected in 1840; since that period there have been no serious falls of the cliff, here about 60 feet high. The lower 5 feet is of black conglomerate, then follow 10 feet of red car stone, then 6 feet of red chalk, (green sand formation), and then 20 feet to 40 feet of white chalk, in hard horizontal slabs. The white chalk dies away to the southward, leaving red only; then that ceases, south of the new hotel, where there is a groyne, and where commences a low sandy foreshore, fringed with 'meals,' forming the east side of the Wash. South of Hunstanton, there is a well-defined belt of shingle, which has found a resting-place on the east side of the Wash, forming the sea barrier to the extensive tract of marshes below the high-land formerly overflown by the sea. Southward, belts increase in breadth and number, and are difficult to trace, from being grass-grown and mixed up with the marsh. In position, these immense deposits of sea-drifted material are very similar to those collected at Sandown and Sandwich, in Kent, each formed under chalk promontories, and protecting large areas of marsh. This belt of shingle, extending from Hunstanton to Woolverton Creek, in an uninterrupted crest, except where intersected by creeks, is 8 miles long, formed on the summit of the 'Stubborn' sand, and it is curious that, in the majority of the numerous reports that have been written and published on the Wash Estuary, its existence has been almost ignored, and the whole of the littoral deposits have been treated as silt only. Woolverton Creek is at present the boundary of the Norfolk Estuary Works. Had the more extensive project ever been attempted, a travelling shingle would

have formed on, and run along, the walls towards the entrance.[1]

Immediately south of Hunstanton, the low sandy foreshore has three groynes, across the upper part, at the foot of which is collected 'debris' of red and white chalk; the groynes retaining 'fulls' of sand and fine shingle, backed by low sand 'meals' fronting the Marsh. The third groyne, between the cliff and the rifle butt, retains a large amount of shingle, driven up the estuary by N.E. winds, and a general southern movement now prevails. The beach is 5 feet higher on the north than on the south side of the groyne, with those winds. In front of Heacham Park, between the shingle 'fulls' and the fallow, there is a belt of from 80 yards to 90 yards in breadth of ancient sea-beach, grass-grown; and between the creek, which runs more than a mile parallel to the shore, deflected upwards, and the present beach, there is a belt of grass-grown sand and shingle. At the outfall there is a lofty overlapping horn of shingle, and below, scattered over the foreshore, there are 'debris' of white and red chalk from Hunstanton. Above the creek, the shingle narrows, and there are numerous groynes projecting from the last, or outer sea-wall in advance of the saltings; 'fulls' of fine shingle being driven up between them over the saltings, which appear, of late years, to have retreated along this portion of the shore, many of these close-piled groynes standing quite out of the shore, 5 feet in height, with pebbles of the old shingle 'fulls' in the joints, and the piles bared in places down to the points.

A large ness of shingle has grown on Snettisham Creek, deflected more than a mile S., until it joins Woolverton Creek. Here there are four or five modern 'fulls;' then a series of ancient ridges, grass-grown, up to the meadow lands below Snettisham. A barn with farm buildings, erected in 1813, on the main marsh wall, is surrounded by a waved surface of ancient grass-grown shingle. All the low land, from Hunstanton past Heacham, Snettisham, Sandringham, down to Woolverton Creek, and towards Castle Rising, appears a ness of shingle, and back saltings formed on the various creeks, enclosed by it. It has the same appearance that is presented by all similar formations. The ancient 'fulls' are at an acute angle to the existing littoral belts: within this shingle belt, up to the spurs of the chalk downs at Heacham, and the Carstone formation southward, is a tract of marsh. The angular and older belts may be particularly traced where Woolverton Creek, after being joined by Snettisham Creek, retreats land-

[1] The area from which the sea has recently been excluded is the head or S. end of the 'Estuary' area, and only about one-fourth the distance above referred to.—J. B. R., 17th July, 1865.

ward towards Woolverton, and turns round subsequently toward the Wash. The triangular peninsula thus formed is entirely shingle, driving the Creek upwards.

In the recession of the high land between the spurs of the downs, at Snettisham and Woolverton, acres upon acres of beach may be traced. It appears to be the 'Shingle End' of this district. At right angles, nearly, to the crest of the present beach, nine spring 'fulls,' with intermediate neap 'fulls,' and their separating valleys, may be counted, partially grass-grown. Behind these there is another series, six in number, more solid, and grass-grown, up to the horse-shoe turn of the creek. All these 'fulls' terminate in horns, curling round inland to the eastward, and the intervening spaces between these overlaps become saltings. Some of these horns of shingle run in a great distance, right up to the bend of the creek, inland; the last has formed a series of eccentric double horns, or crescent curves, with a shorter radius. As each serial 'full' of shingle overlaps the last, the creek is driven upwards, at its outfall, and the low sandy foreshore and saltings, above, are proportionately impinged on. On the upper side of the creek, there is no stone whatever; but the well-known warp of the Wash Estuary alone. The range of spring tides is shown round the last horn, by a series of banks of shells, of crescent shape, formed on the shingle. The last horn has a steep bluff end, right into the creek side, like the end of an artificial mole, the base of the slope terminating at the creek. The shingle that has thus crept, snake-like, up shore, in parallel bands, has hitherto found a place of rest on the marshy foreshore. It becomes an interesting question, where it will ultimately deposit, if the 'Peter Black' sands are 'inned' down to Woolverton Creek.

This Paper is illustrated by a series of diagrams from which Plate 2 (Figs. 1 to 5) and the Woodcuts (Figs. 1 to 16) have been compiled.

[Mr. Redman

THE EAST COAST OF ENGLAND
FROM THE THAMES TO THE WASH.

SKETCH MAP OF COAST

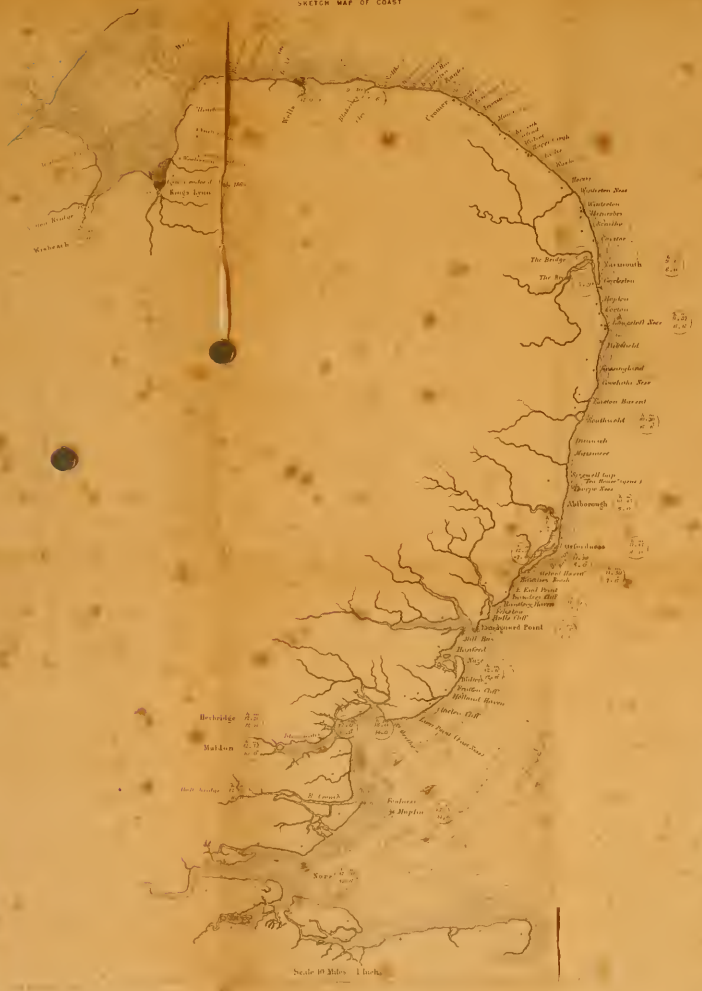


Fig 1

A CHART OF ORWELL HAVEN OR RATHER HARWICH ROAD SHEWING PROJECTED FORTIFICATIONS
BY HEN LEE 25TH MEN 8TH ILLEGI COTTON MSS

Fig 4

ORFORDNESS,
TIME OF ELIZ. COTTON MSS.

SOUTHWOLD HARBOUR
COTTON MSS TIME HEN 8TH A.D. 1509-47

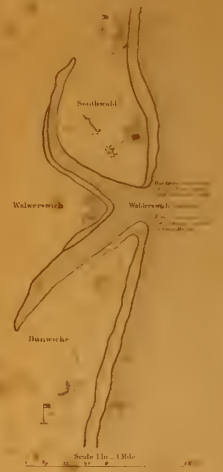
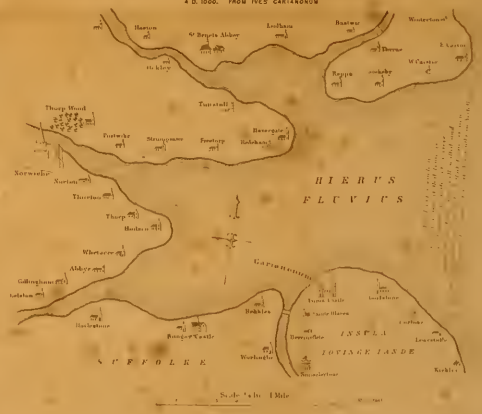


Fig 2

LANDGUARD POINT
COMPARATIVE STATES OF.

Fig 3

ANCIENT CONDITION OF THE WATERS NOW FORMING YARMOUTH HAVEN
A.D. 1000. FROM RYE'S CARIANONUM



Scale 2 Ins. 1 Mile

Mr. REDMAN said, that a few facts had come to his knowledge since the Paper had been prepared. He had referred to the modern buoyage of the Prince's Channel as being deeper than the Queen's Channel to the south of it, to illustrate the changes in the Thames' estuary. From the most recent surveys of the sand-banks and channels, it appeared that other changes had lately occurred in the first-named channel. The west entrance, the Girdler Channel, had, two years back, been superseded by a channel more to the N.E. between the West Girdler and Shingles, called the Shingles Channel, up to the arrival of the Princess Alexandra, who passed through it, subsequently it was called the Alexandra Channel. Owing to the breaking away of the crest of the West Girdler sand, the western outlet of the Prince's Channel, the Girdler Channel, was rapidly shoaling, and the Alexandra Channel had also lost depth, but at the east end of the Prince's Channel, between the Girdler and Long Sands, Bullock's Channel had broken through the sand separating its deep-water head from the 'Black Deep,' and at that point it was now 20 feet deeper than shown in the last-published charts. This channel, not yet buoyed, was 3 miles long, and 1 mile wide, and 40 feet to 50 feet deep, throughout. Should the west approaches to the Prince's Channel continue to shoal, the lights would in all probability be removed, and the Bullock Channel, leading into the 'Black Deeps' of the South Channel, would be lighted and used instead. This channel would be wider and freer for navigation, but would be $1\frac{1}{4}$ mile longer.

The Middle, and Overland Channels to the westward were also shallowing. Silting-up, to the extent of 9 feet, had recently taken place at the former, as there was now only 5 feet depth of water, where 14 feet formerly existed. The Margate, Tongue, and adjoining sands all tailed out, or extended S.E., and there had been a general shifting of the buoys in that direction this season. The 'Knock' sand forming the north boundary of the South Channel had tailed out to the S.W., partaking of the movement of the sands referred to in the Paper. These changes were all due to tidal agencies, the breaking away of the crests of the sands being also partly caused by wind waves.

Respecting the upper reaches of the river, he found that he had somewhat under-stated the depths, his information being derived from the last-published charts, as nowhere, from London Bridge to Woolwich, was there now less than 12 feet at low water in the Mid-Channel, in lieu of 10 feet as stated in the Paper. In Halfway Reach, Daggenham Shoal was reduced by scour and dredging to a small spit in the centre, with 11 feet over it at low water, and a channel on each side 15 feet deep, meeting the deep water above and below of 20 feet. In Erith Reach the 'Rands' shoal was also reduced to one-third the width of the navigable channel at

low water, with a channel on the north side 20 feet deep, and a channel 15 feet on the south side.

At Harwich the 'Beach End' buoy, moored in 18 feet of water, laid in 1842, was shifted each year, and last moored in February, 1863. He did not know the amount of movement each year, but it would in all probability closely coincide with the late Admiral Washington's estimate, of 12 yards per annum. By comparing the Admiralty surveys of 1842 with others of the present time, he found the S.W. progression in the last twenty years, was 200 yards, equal to 10 yards per annum.

Respecting the engineering and commercial value of the question, he had prepared from Mr. Ingham's shipping returns for the years 1856-1859 and 1862 (Appendix) the registered tonnage of the thirteen ports from Maldon to Boston, within the limits of coast described. It would be seen that the aggregate registered tonnage—nearly a stationary quantity for the last seven years—was nearly 130,000 tons; and the amount of exports and imports, coasting, colonial, and foreign, from the various ports along the coast reviewed, was nearly $1\frac{1}{4}$ million of tons; the colonial (a small amount) nearly stationary; the foreign slightly falling off, and the coasting considerably so, for that, on the whole, there was a falling off due to the extension of railways and the diversion of the carrying trade to London. Still the amount of tonnage was considerable. Yarmouth had a tonnage more than equivalent to Harwich and Ipswich combined. Lynn was the second in importance, whilst ports like Orford and Southwold had practically ceased to exist, as they were not represented in the Parliamentary Returns.

As an example of works for the protection of a particular frontage, he might refer to Cromer, where, by local information received since the Paper was written, the north groyne recently erected had raised the foreshore 16 feet, and those to the southward of it had raised the foreshore by steps of 6 feet down to the ordinary level of the beach.

THE ASTRONOMER ROYAL referred to the Chesil Bank, and to the phenomena which took place there, as affording a key to many of the natural operations which had been detailed in the Paper. It would be remembered, that Mr. Coode's conclusion in regard to the Chesil Bank, was, that the drift was from west to east[1]—that was from Bridport or Lyme towards Portland,—and this assumption was supported by geological observations. There were several specimens of well-characterized stone, particularly one which seemed to be a species of jasper (bloodstone) which appeared

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xii., p. 520.

'in situ' in the neighbourhood of Lyme. It was found in that part of the Chesil Bank which approached the vicinity of Portland, though no beds containing that stone could be discerned in Portland itself. This appeared to be the leading fact which led Mr. Coode to suppose that the drift was in the direction from Lyme to Portland. There was one thing to be observed—viz., that there was a great, but gradual difference in the size of the stones in different parts of the Chesil Bank. The stones of the bank near to Portland were large, and they went on decreasing till they became small pebbles, or almost sand, at the western extremity; and the question was whether that difference in the size of the stones could be reconciled with the notion of the drift being from the west to the east? There were circumstances which admitted of numerical computation in the drifting of stones, to which the attention of engineers could not be too strictly called. Thus in numerical relation, if the velocity of a current were doubled, it would carry stones of sixty-four times the weight of those carried before. It was the only instance in physical science, with which he was acquainted, in which the sixth power came really into application. Supposing that a stream with a certain velocity would carry stones of only one ounce, if the velocity of the stream was doubled, it would carry stones weighing 4 lbs. At the same time it was to be considered that every current must gradually lose its speed, and at last come to a state of rest. It would be seen that the first part of that current, when in full force, was competent to carry large stones; that as it went further on, it was competent to move small stones; and going further on still, it was only competent to move pebbles and sand; and they might take the gradual diminution of the size of the stones thus transported as an indication that the travelling motion had been from the great stones towards the little stones. He had considered the question for years, and was satisfied, that the travelling of the stones would not be from the side where the small stones were deposited to the side where the larger stones were deposited; but that it must have been in the opposite direction. He therefore found himself in this difficulty as to Mr. Coode's theory. On the one hand there was a mechanical law which he could not give up; on the other hand, he had this geological indication to which he could not attach a doubt, that on the Portland end of the bank, stones were found, which were only met with 'in situ' at the other end of the bank. How was he to get over this difficulty? for difficulty it certainly was. As he had said, he could not give up his mechanical point of the travelling from the east to the west, yet there was this apparent evidence, on geological grounds, that the travelling was from the west to the east. Being in this difficulty, he must be forgiven if he made a strong supposition. After consideration, the only

one he could come to was this ;—that the materials which formed that bank were piled up by the sea ; that they had been torn up by the violence of the surf from the bottom of the sea, and that then, by the continued action of the surf, they had been piled up by degrees, and afterwards had received some slow motion along the coast ; and he was obliged to attach to this the additional supposition, that in that part of the bay under Portland which they were unable to examine, there were strata which furnished these coarse blood-stones which had caused the difficulty of explanation on this occasion. With regard to the mechanical possibility of such a state of circumstances he had no doubt. He had witnessed the surf during a heavy gale on the Chesil Bank, and had observed that it was upwards of 20 feet high, and came on with a shock which was scarcely conceivable ; and when it was remarked what tidal currents could do in other places, where the currents and their effects could be well examined, it might be imagined what this surf would do, and what the neighbouring wave-disturbance would do, which was of a character so much more violent than the quiet currents of the tides. It was well known that a quiet tidal current would plough up the bottom of a channel in narrow places. Some years ago he examined the state of Wexford Harbour, where there was a considerable back-water. The tidal currents in the narrow mouth had ploughed a channel to the depth of 50 feet, and had then deposited the matter in front of the harbour, leaving not more than 5 feet depth of water. In like manner, the scour of the tide at Liverpool had ploughed out the confined channel to the depth of 60 feet, and had deposited the matter northwardly in the sands, which made Liverpool a bad harbour, and southwardly, in such quantities as to be rapidly filling up the head of the estuary of the Mersey. It appeared to him that the power of the sea in tearing up the bottom, and washing the debris towards the land, must be considered the principal agent in forming the shingle banks which were described in the Paper.

There was one place, with which he was well acquainted, which had attracted a great deal of attention—the harbour of Harwich. It was quite correct, as was stated in the Paper, that the sea-cliff on the north side of the harbour (towards the Walton of Suffolk) was inland to a considerable distance, and deposits of stone or shingle had been piled up under it : and in later times it was known how much discussion had taken place as to the injury done to the entrance to Harwich Harbour. He was a member of the Tidal Harbours Commission, and one of the subjects brought under the consideration of that Commission was the injury to the entrance channels of Harwich Harbour ; and Admiral Washington considered that the abstraction year by year of large quantities of Roman cement stone had occasioned the

continued advance of Landguard Point. It was to supply the place of the stone taken away that the new pier was built at Harwich, which, however, he believed had not proved to be of the smallest beneficial effect; and looking to that fact, and the strange way in which the advance of the point at Landguard was going on, it seemed that the tidal currents, which depended on the entrance and exit of the water in the Stour and Orwell, had very little to do with the matter, but that there was some unknown cause, which he conceived to be that which he had taken the liberty of suggesting. He thought it very likely that the same cause had to do with the formation of the shoal in front of the mouths of the Ore and the Alde. The formation of the shoal from the sea, and possibly some degree of southern travelling of the sea-shore, had compelled the rivers to seek an exit through a more southerly part of the shingle.

Mr. C. H. Gregory, V.P., said, he would not attempt to reconcile the apparent differences between geological observation, and the theory laid down by the Astronomer Royal. At the same time, he thought that engineers considered that where shingle travelled, it generally followed the direction of the prevailing winds which blew along the coast affected. Thus, on the south coast, which was exposed to winds from the west, the travel of the shingle was, for the most part, from the west towards the east; while on the north and east coasts, the prevailing wind most affecting the action of the sea, being from the north, or north-east, the shingle would travel from the north, towards the south.

All who remembered the previous Papers laid before the Institution by the Author, would be prepared for a large amount of information in the present communication, which, he thought, was in no respect inferior to those which had preceded it. He thought the Members were much indebted to the Author for laying before them the results of a large amount of patient, laborious investigation, and very careful practical observation, instead of endeavouring in one sense to make his labours more profitable to himself, by their publication in the form of a book. He hoped that the Author, or some other gentleman who had studied this coast, would supplement this interesting Paper, by some further particulars of engineering works for the improvement or development of harbours, the protection of the coast from the encroachments of the sea, or the reclamation of land from the sea itself.

Although he had no intimate knowledge of the East coast, the Paper suggested to him one or two subjects for observation: In the first place, it was seen that along this coast, as elsewhere, Nature supplied, in many places, Engineers with the means of protecting the coast, by taking advantage of the general travel of the shingle

in one direction; the construction of groynes to accumulate that shingle in a natural foreshore being an obvious means to prevent the encroachments of the sea upon the land. Again, where there were rocks on the shore, these might be detached at low water and drawn up by crabs, and laid as a rough bank, or wall in front of the land, or groynes might be formed of these rocks, at a saving in first cost, and also in maintenance, as compared with timber groynes, which often cost as much as £200, and became worn out so rapidly that the cost of their maintenance was more serious than that of their construction. He had used rocks for both these purposes with success about twelve years ago. He suggested, as an interesting subject for investigation, what proportion the amount of land lost by the encroachments of the sea bore to the amount of land which, by natural or artificial means, may have been reclaimed from the sea. He had observed great irregularity of action in these encroachments, even on shores of the same material. On some parts of the coast of Kent, he believed, that the chalk cliffs were subject to serious loss from the sea; while in those near Freshwater, in the Isle of Wight, with few exceptions, the form of the cliffs had been very slightly altered for many years. A marked difference would naturally occur in the effects of the sea upon different soils, and the most serious loss would be found where the cliffs were exposed to the combined effects of land water and sea water. It seemed that in the Frinton Cliffs, and at the Naze, in the attempts made to save the land from the encroachments of the sea, the evil effects of the land-water had been lost sight of. He believed in both these cases the soil was London clay, or some formation similar to it: and those who had experience in London clay must have observed the presence of a large quantity of water which would force its way through or under it, and find an outlet at any exposed face. Such water was a fruitful source of slips, which could only be stopped by deep drains, cut down to the seat of the slip, or driven in by headings, with deep catch-drains at the back of the slip. He did not understand that any such measures had been adopted at the places alluded to; but while the land water was allowed to act unchecked, the protection of such a shore from sea water alone, would not prevent its loss.

While he had alluded to some of the measures which might be adopted for preventing the encroachments of the sea, the economical consideration of any such measures ought not to be neglected; for there were many instances, where the value of the land to be saved from destruction would not repay the outlay which would be necessary for its preservation.

Mr. C. Vignoles remarked, that the subject introduced by the Astronomer Royal, was of such importance, that it deserved to be

considered a little more closely. He concurred with the Astronomer Royal, as to the mechanical law with respect to the effect of the difference of velocity, in moving different bodies of various sizes. On the Chesil Bank, all the large stones were on the eastward, and, to the westward, the stones diminished in size, till they became pebbles and gravel. He conceived there might be two causes acting to produce this result. In the first place, where there were certain currents, and violent action of the sea, the larger bodies might be deposited in the position in which they were seen, and then, the prevailing winds might cause the travel of the shingle from west to east. As regarded the powerful action of the sea, those who had seen the violence of the waves must allow, that there might be, at certain distances and depths from the shore, geological strata or matters which would produce the effects which were noted on the Chesil Bank—viz., the deposition of large material at the east end, and of small material at the west end. This might arise from two different causes, in the same manner as the changing of the channels at the mouth of the Thames. That could not be attributed to a change of the prevailing winds, or to the travelling of the shingle, but must be the result of currents, acting independently of these. He considered, in the varying cases of the coast, no empirical rule could be established. The changes which took place could not be attributed to one cause; but in many cases there was a combination of causes. The tendency of the wind produced a travelling motion of the shingle in a given direction, and, at the same time, there was a deposition of materials on the bank in an opposite direction. Both states of things were reconcilable, and both resulted from natural causes.

It was quite clear that not only at the mouth of the Thames, but also in the Ganges, the most important changes were going on, so much so that the channel in the Saugur Roads, in which vessels formerly anchored, was now closed up, in consequence of which vessels were obliged to make for the river direct, without going into Saugur Roads, and in contrary winds they could not anchor, but were obliged to keep out at sea. Those were changes which could not be effected by any other causes than a combination of sea currents. At the mouth of the Thames the sea currents, combined with the land water in the Thames, had more or less produced the changes in the channels. There was nothing more important in the business of the engineer, than the conflict and changes which were taking place at the mouths of these great rivers.

Sir JOHN RENNIE (Past-President), differed from the Astronomer Royal with regard to the movement of the beach or shingle. It appeared to him, to arise chiefly from the disintegration of the cliffs, or rocks along the adjacent shores. These were undermined

by the constant action of the winds, waves, tides, and currents upon their base, and the rain-water and atmosphere acting upon their summits. Large masses thus fell down from above, and formed an extensive talus, or slope at the base of the cliffs; this was again acted upon by the same forces; so that the softer materials were held in suspension by the waters, and transported away according to the direction in which they were impelled, and deposited in the neutral lines where those forces cease to exist. In the same manner, the harder materials were rolled, or forced along the shore, thus forming the great banks of shingle which were observed in numerous parts of the southern, and eastern coasts of England. When the waves acted directly at right angles to the coast, the masses of beach and sand became stationary; but when they acted obliquely, they were moved forward in the direction of the prevailing winds. The ordinary currents had comparatively very little effect upon the onward movement of the shingle, or beach, which was mainly caused by the continual impact of the waves. It was true that, upon extraordinary occasions, when the waves attained unusual altitude and force, the shingle was driven up from greater depths, but, generally speaking, this was not the case, unless under unusual circumstances. The cause of the roundness of the pebbles, arose from the continual attrition of the masses of shingle against each other. As the shingle and sand travelled in the direction of the prevailing winds, tides, and currents, so would the supply be in proportion to the energy and violence of these causes, and the degradation of the adjacent cliffs and shores; and in the same ratio must measures be taken by means of groynes, piers, and other works, to prevent their injurious effects upon the different harbours, rivers, &c., lying within their reach.

Records of the coast, and the successive changes which had taken place in it from time to time, as well as the causes which had produced them, and were still in operation to produce further changes, were most valuable to the Civil Engineer and to the Mariner. Without knowing and carefully studying the operation of these natural phenomena, it would be in vain for the Engineer to attempt to design any work which might be intrusted to his charge for the improvement of rivers, or harbours along such a line of coast, for most probably the works would prove to be abortive, and the money expended upon them would be in a great measure thrown away. Of the consequences arising from the neglect of such preliminary investigations, there were unfortunately too many examples; amongst others, he might mention the attempt of the celebrated Smeaton to improve the harbour of Rye, by making a new mouth to the westward of the old one, which was effected in the first instance at a great expense, and a few years

subsequently was filled up by the beach travelling from the westward. In that case, the proper course would have been to have selected the line, where the two currents of beach met and neutralised each other, and to have protected the entrance by piers, groynes, and other works which would have required to be advanced occasionally in proportion as the supply of beach or shingle accumulated from one side, or the other. Another important example might be seen at Harwich, where a fine natural harbour had been materially injured by the construction of a pier, on the wrong side of the entrance. From a very little reflection and knowledge of the natural causes in operation, it might have been ascertained, that the continual prolongation, or advancement of Landguard Point, to the southward and westward, was due to the line of beach and sand being driven by the northerly and easterly winds and currents, which operated so powerfully along that line of coast, and that to prevent further injurious results, it would have been necessary to carry out a pier in a proper direction from Landguard Point, and to have assured its successful working, by a series of well-contrived groynes, and other works to the northward.

He might also mention the harbour of Lowestoft, where there was not sufficient back, or returning water to keep the entrance open without continual dredging. It was, however, true in this instance, that notwithstanding the expense of keeping the harbour open, it might even now have proved worth the money expended upon it. He would further remark, that all rivers on the east coast of England were compelled to prolong their course parallel to the coast, for a certain distance, until they accumulated sufficient water to force themselves into the sea, from the same causes as those which occasioned the extension of Landguard Point. Rivers, such as the Ald, the Ore, the Yare, &c., as well as the entrance to Yarmouth Roads, might be considerably improved by guiding the sands in a proper direction, in the same manner as was now being done in the improvement of the mouth of the Ouse into Lynn Deeps, in the Great Wash, and which had already been effected to a considerable extent in the Nene, Welland, and Witham rivers.

Capt. BURSTAL, R.N., was acquainted with the greater portion of the coast described in the Paper. Between Margate and Orfordness considerable changes had taken place in the channels on the south portion of the estuary of the Thames; whilst the channels in the north part—the Swin, and the Wallett, approaching towards Harwich—remained as nearly as possible in the same form, and retained the same depth, as was shown on the chart of Graeme Spence in 1792. On the south side, the Shingles, Margate Sands, and the Girdler had each undergone changes,

which he attributed, not so much to the action of the winds, as to that of the currents. The two channels referred to in the course of the discussion, namely, the Shingles—now called the Alexandra —and the Bullock, were known to him as far back as the year 1837, but they were not then of sufficient depth, nor was the tide running sufficiently fairly through them, to make them worthy of notice for navigation. As far as the eastern channel was concerned, between the Shingles and the Girdler, when he was employed in surveying, he always went out by that channel with no other guide than a bearing of the North Foreland lighthouse. Though he had not seen a recent chart, he believed the depth remained about the same in some of these channels; his reason for thinking so was that a large portion of the stream, from half flood to high water, as well as the last portion of the ebb stream, for a considerable time, ran strongly through these channels, so that it was to be hoped, that the stream would continue to keep them open. If the channel on the east side were to silt up, there would still be a good approach from the North Foreland to the entrance of the Thames. Assuming it to be correct that the depth through the Bullock's channels was, as stated, 40 feet, there was a much greater depth now, than during the period he referred to, when there was not more than 20 feet of water through it, and vessels drawing more than 13 feet of water waited in the Queen's channel, as they could not cross the flats until the tide had risen.

There was one feature of the coast, which he thought had escaped the notice of the Author. He referred to that part of the coast between Shoeburyness, and the entrance of the rivers Crouch, Blackwater, and Colne. The coast between the Blackwater and Crouch, and thence to the entrance of the Thames, had gradually encroached upon the sea, and, with the assistance of artificial means, an immense amount of land might be reclaimed from the sea. He knew from personal observation, that many hundreds of acres had been enclosed, year after year, by the farmers, and he particularly referred to Foulness, where several plots of land had been so enclosed. Taking into account the relative amount of accretion and reclamation, he thought that, between the Thames and Orfordness, more land had been gained from the sea, than the sea had gained from the land. There could not be any doubt that the cliffs at Clacton, Great Holland, and the Naze were rapidly wearing away, from the combined action of the land springs and the sea water at the base. The cliffs were falling off in the same way at the Isle of Sheppey, and it was probable they were of the same geological formation. It was questionable whether it would be possible to retain them by artificial measures; and, even if it were possible that the land could be saved, it would probably not repay the outlay.

As to the manner in which the beach travelled on the east coast, if he recollected aright, there was no shingle between Harwich and the Thames, the ending of the shingle being at Landguard Point; and, from his observations, both on the east coast, and on the south coast, the beach did not travel with the prevailing wind, but with the prevailing sea. The prevailing wind at Harwich and Orfordness was south-west, nearly the same as at Dover; but the heaviest seas at Harwich and Orfordness were from the north-east, and he had come to the conclusion, that the shingle travelled to leeward, away from the prevailing heavy sea. There was abundant evidence to show that the large accumulation of beach at Landguard Point had come from Felixtown. The bricks, from old houses that had fallen into the sea at Felixtown, had been found deposited at Landguard Fort. It was to be regretted, that the breakwater recently constructed at Harwich, from Beacon Cliff, had failed for the purposes for which it was erected. The littoral tides could not have much effect upon the shingle, because they were never strong in-shore, yet when the current was strong and impinged at an angle on shingle banks, this would wear away. With respect to the inside of Landguard Point, the combined action of the streams from the rivers Orwell and Stour created a velocity of current equal to 5 statute miles, or 4 knots per hour, and the current did not run straight along the coast, but set at an angle upon the hollow by the south part of the point, and there the beach was stopped. Seeing the action of the current on the beach outside the point, and the beach accumulating on the east side of the point, engineers would be enabled to determine in what way they could prevent the progress of this drifted shingle, which would certainly before long stop up Harwich Harbour.

Dungeness Beach presented nearly the same appearance as that of Orfordness. The travel of shingle at Dungeness was with the prevailing wave coming from Rye Bay, where the ridges of shingle were broken short off on the western side. The accumulation took place after passing the lighthouse, and formed the extension of the point on the east side of it. A similar process was going on in the opposite direction at Orfordness. The view of these ridges of shingle from the top of the lighthouse was very interesting. It was difficult to say whether shingle came from the bed of the ocean, or not. He could state, however, that in the course of his surveys, the only instance in which he found real shingle at the bottom of the sea, was off Hastings, at a distance of about 7 miles, and so remarkable was that circumstance that he designated the locality Shingle Bank; the depth upon it was about 10 fathoms. Off Dungeness he found clear sand, and off Orfordness the same.

Mr. Hawkshaw, Past President, said the Astronomer Royal

had raised an interesting question. It was, however, one for which it was possible to find a satisfactory solution. He had observed, during his residence in South America, on many occasions, at the mouths of the rivers which ran into the Spanish Main, extensive mounds of large stones. There were mountains 100 miles from the mouths of these rivers, and similar stones were also found along the whole course of the rivers, but intermixed with smaller stones and débris. It was, however, only at the mouths of the rivers that these extensive accumulations of large stones were found. It was incontestable, that the greater the velocity of current, the heavier would be the stones transported by it, and therefore if the question were treated on that principle alone, it would seem as if the current flowed up these rivers, instead of down them. There could, however, be no doubt that these stones came down the rivers, and the fact was, that these larger stones were transported with smaller stones, by a current strong enough, at certain times, to transport both, to a point where they came in contact with other influences, which carried off the smaller fragments, and left the larger stones behind. He had noticed these phenomena repeatedly, and he thought they might explain the difficulty of the Astronomer Royal with regard to the Chesil Bank. It was evident, if a coast existed of a certain form, and if there was a current along it, of such a velocity (whether from the wind or the set of the sea was immaterial) as would transport stones of a certain size, say of the weight of two, or three ounces, it would likewise transport smaller stones, and these stones, of various sizes, would be found on the beach; but, wherever that beach projected into a current of greater velocity, the small stones would disappear, and only the larger stones would be left. Thus, at the eastern point of the Chesil Bank, might be found gravel of large size; and further westward, it would, to cursory observation, appear to be of smaller size; but this would not prove that the current came from the eastward.

Mr. J. Scott Russell, V.P., confessed he took the view of the Astronomer Royal as to the Chesil Bank stones. He had no doubt whatever—for he had seen that enormous sea breaking on the Chesil Bank—that the great western swell extended with almost unmitigated effect down to the bottom of the channel, where it swept, and rolled, and chafed against the bottom, in places where the larger stones existed. He believed that those deep waves in the deep water brought these heavy stones straight to the high part of the Chesil Bank. The Astronomer Royal had correctly stated, that the power of waves, or rather of water in motion, to knock about heavy stones and throw them upon a bank, was in proportion to an extremely high power of the velocity. He did not know whether all, who had considered the subject, were agreed whether it was the sixth power of the velocity, or not. Perhaps the

Astronomer Royal would say if he calculated what was called power, as the mass multiplied by the square of the velocity. If by that he meant the power to lift stones to a given height, the sixth power of the velocity would not be obtained according to that particular view. It was an observation of his, which had been confirmed by many observers and engineers, and he thought was consistent with the Astronomer Royal's calculations, that they could not have a higher breaking wave, of the nature of a swell, than a wave whose height was equal to the depth of the water. The power of a wave, breaking from a height of 16 feet, would be a power to produce a velocity of the water of 32 feet per second, or 19 knots per hour, at the instant of breaking. Such a deep-water wave would have power to transport and raise up a very large stone. More in shore, where the waves broke in 10 feet of water, the highest velocity of the water in the breaking wave was reduced to 15 knots per hour, and in 5 feet depth of water, 11 knots per hour would be the highest possible velocity of the breaking wave. Applying these facts to the question of the formation of the Chesil Bank, he would notice that, in proportion as the general foreshore shallowed inland, the smaller were the waves, and the smaller were the stones which were found on the beach, and for like reasons the large stones were found in the deep water, which happened to be at the outer end of the Chesil Bank.

He thought it was important to distinguish between the prevalent wind, and the prevalent wave, because, as far as he remembered Dungeness, which was one of the most remarkable of these beaches, the ridges of beach went completely round the lighthouse, and it appeared as if Dungeness were travelling out to sea, equally from both sides. He had stood upon the top of the lighthouse, and had seen the breaking waves come from the sea, in circles which embraced the Dungeness Point, so that, from all directions round the same point at the same time, these great deep swells were breaking on shore, and sweeping up large pebbles, and this occurred although the wind was opposed to half of the sea which was breaking. No doubt, the great sea wave was propagated in the direction in which the wind was blowing out on the ocean. Further than this, he thought they had been made aware by experiments, that the wind-waves themselves, so long as they were mere wind-waves, picked the beach off the shore, instead of accumulating it, and it was the ground-swell from a great distance which drove it up. For these reasons he considered, that the direction of the prevalent sea was much more important in the formation of beaches, than the direction of local and prevalent winds.

The Astronomer Royal, in explanation, said that it was possible he might not have stated sufficiently his ideas as to the formation of shingle banks. From what had transpired in the

course of the discussion, it seemed to be assumed, that he had meant to ignore the travelling of the shingle—but that was not his intention. His object had been to show what he believed, in many cases, to be its origin. He had trusted that his views might have been understood from the remarks he made as to the difference of rates and extent to which shingle and small stones would travel under the action of currents, or under the action of oblique surf. He did not ignore the action of the current, or the surf, but he thought that in many cases the origin of the shingle was not from the degradation of the cliffs, but that it was produced to a far greater extent by the ploughing up of the bottom of the sea.

He would advert to one part of the coast to which frequent allusion had been made—Landguard Common. He was well acquainted with the Orwell and the Deben, and with the coast for some distance beyond those rivers. Proceeding from Landguard Common, where the inland cliffs commenced, to the Deben; at first the cliffs were of crag entirely—there was scarcely a stone in them. The cliffs of crag were followed by cliffs of the London clay, in which there were a few petrified bones and whales' ribs, but no stones. Then followed the cliffs of Bawdsey, which were of London clay. And in front of all these cliffs of London clay there was a foreshore of London clay running out to a considerable distance. In all this cliff range he could not conceive there was any material whatever for forming the extensive shingle point of Landguard Common. But there was another origin which, he would suggest, had some plausibility in it. Every geologist knew, that below the London clay there followed what was by a misnomer called the plastic clay formation, as it consisted for the most part of pebbles, the best specimens of which, in the neighbourhood of London, were to be found in the localities of Plumstead and Blackheath. He apprehended that those pebbles underlaid the London clay and crag, in the neighbourhood of the coast of which he was speaking, and that they had been thrown up in those vast quantities which had formed Landguard Common. He thought it probable, that they had formed the bank which interrupted the course of the Ore and the Alde, as well as the coast-line further up; and such, he believed, was the origin of the great shingle point which had attracted so much attention.

There was one practical inference which he drew from this theory,—supposing such a theory to be true (of course he spoke hypothetically)—it was useless to construct long piers to stop the accumulation of the shingle, because it came from a place on which the piers had no effect. He did not apply this reasoning to the cases of Folkestone, and Dover, where the shingle was almost constantly drifting; but there were other places, such as

he had noticed, where the accumulation of shingle could not be stopped, because the formation was going on in the depths of the sea, where no artificial works could control it.

He would add, by way of further explanation, that he was well acquainted with the neighbourhood of Swansea, and the bays in its vicinity, and from his observations in that locality, he had been enabled to lay down the general rule, that in a bay, whatever was the tendency of the prevailing wind, or prevailing surf, the drift of the pebbles was always inward, from the horns of the bay to the centre of the bay. That, as he believed, was the case in the instance of the great bay between Portland, on the one extremity, and the Start Point, or rather Dartmouth, on the other extremity. The drift was inland to the centre, with pebbles at the points, diminishing to fine sand in the bight of the bay. Returning to the subject of the transmission of shingle from the sea, there were various places, such as the Chesil Bank, for instance, and another place, a little beyond Dartmouth, called the Slapton Sands, where there were banks of shingle and sand, leaving a fleet, or backwater behind them. He could hardly imagine a formation of that character to have taken place, except by the action upon the bottom of the sea, which he had mentioned. It could not have been formed, by drifting, as then the beach would most likely have filled up inside as well as outside. It would be desirable to have some further notice taken of such places. There was another locality he had seen, which was deserving of attention; he alluded to the portion of the south-eastern coast of France, situated between Narbonne and Perpignan, where extensive banks enclosed large sheets of water, called by the general name of 'Etangs.'

Mr. JOHN COODE said, there could be no doubt, as was stated in the Paper, that the Orwell and the Stour did at one time flow to the sea in a more easterly direction than at present; nor could there be any doubt that the growth of the Landguard Point had been very great. About two years and a half since, he was employed by the Government to report on that matter. In the Paper the growth was put down, chiefly, he believed, on the authority of Admiral Washington, as being at the rate of 10 yards per annum towards the south-west. By a close comparison of a chart he had made in 1861, with one made in 1804—fifty-seven years previously—he found that the growth had not been less than 705 yards, being at an average annual rate of $12\frac{1}{3}$ yards per annum.

With the special object of determining the course in which the shingle travelled, he had caused observations to be made, at three different points: first, on the south-west of the harbour opposite Dovercourt; next, opposite Dairy House; and next, opposite the

entrance to Handford Water; and at neither of these points was there any shingle below the low-water line; in fact, very little on the beach itself; but, beginning in 2 fathoms' depth of water opposite Dovercourt, and approaching the shore as far as the low-water line, the material was all soft mud of dark colour: opposite Dairy House it was mud and shell-fish, then clay and sand, and clay at low water: near Handford Creek it was all soft mud in 2 fathoms, and soft mud and clay at low water. He thought from these facts, it must be admitted, that the shingle had travelled along a great length of coast to the northward, and after a considerable struggle, at the mouth of the River Alde, had diverted the entrance of that river to the extent of 10 miles to the south-west. The shingle had then crossed the mouth of the Deben, and travelled down to Landguard Point, where it was arrested by the influx and efflux of the great volume of water passing in and out of Harwich Harbour.

As regarded the theory advanced by the Astronomer Royal, in reference to the movement of shingle in deep water, the question to be decided was, whether the movement of the shingle was from the deep sea towards the shore, or along the beaches? In fact, was the travel of the course of the shingle oceanic, or was it littoral? It had been observed, that the leading fact on which his conclusions had been based, was the existence of a peculiar kind of jasper pebble amongst the shingle of the Chesil Bank. Now, that was not a leading fact, but a collateral fact, and one which, he considered, was quite confirmatory of the general view he had advanced. The leading facts he relied on were, the relative positions of the materials found on the beaches, and in the cliffs along the shore—whether chalk with flints, ordinary red sandstone, highly siliceous sandstone, or jasper pebbles—the relative position of these pebbles, and the geological formations from which alone they could have derived their origin. In every instance, shingle of any particular kind was always found to the eastward, and never to the westward, of the cliffs which would produce the materials of which that particular shingle was composed. At the western end of the bay, the shingle was first met with on the beaches, near Budleigh Salterton, just below Sidmouth. On that beach there were some pebbles, peculiarly marked as if with blood spots, about which there could be no mistake. Pebbles of that kind, and the jasper pebbles before referred to, were found at the mouth of the River Otter in great abundance. Just above Sidmouth, chalk cliffs were first met with, and there chalk flints were found on the beaches. So entire was the absence of flint shingle to the west of Sidmouth, that the inhabitants of the villages in that locality, could not get flints in their immediate neighbourhood to strike a light with, and they had to send eastward to Sidmouth to

obtain them. That was a strong proof of the entire absence of flint shingle on the beaches west of Sidmouth. Between Sidmouth and Lyme there was a range of high chalk cliffs washed by the sea, and extending some 5 miles or 6 miles along the shore. In these cliffs, flints were found in great abundance, and the chalk flints, together with the ordinary red sandstone pebbles which came from Sidmouth, and the peculiar spotted pebbles, and the jasper pebbles, might then be traced all along the shore to Portland. How did it happen, if the shingle travelled from west to east, that the large shingle was found, or rather seen, only at the east end of the Chesil Bank? He had shown, on a former occasion, that this was the case. The fact was, that large shingle did exist at the west end, but under water. He had traced it from the chalk cliffs, where it first fell from the cliffs on to the beaches, and thence, all along to Portland; but in the western portion of the bay the large shingle was only found under water. From the acute angle at which the waves met the shore in the western part of the bay, sufficient force was not created to throw the large shingle on to the shore; it was there, nevertheless, but moving along under water. Not only was large shingle found there, but there was every indication that it was comparatively fresh out of the cliffs, because in the indentations of the flints the chalk was found quite fresh. He had taken up pieces by the use of a diving-dress, and had frequently found the flints with the chalk quite fresh from the cliff, and from the globular form on quitting the cliffs, they had gradually been abraded, and had assumed a flattened form as they came towards Portland. This was most remarkable in the case of the sandstone pebbles; as might be expected from the material not being so hard as in the case of the flints. He found no shingle below a small depth under water, in the western part of the bay—nothing but sand; and inasmuch as the shingle was found at first only in depths of 4 feet, or 5 feet below low water, and as shingle was not mixed up promiscuously, but every particular kind was always found to leeward of the cliffs, from which only it would seem possible that it could have been originally derived, he thought he was fairly entitled to come to the conclusion, that the shingle travelled along the beach, and not from deep water. He maintained, that these facts militated against the theory of the Astronomer Royal, that the shingle was driven in from the deep sea. If that theory were correct, how did it happen that on the east coast, near Harwich, the 3 miles of coast, extending on either side of the entrance of that harbour to Handford Water, and out to Walton Naze, and directly opposed to the north-east drift, were not loaded with shingle? There were 3 miles of coast running in a south-easterly direction, and therefore directly opposed to the great wave of the North Sea; and if it were true that the shingle moved in deep

water, that line of beach ought to receive a large supply of shingle from the North Sea; but such was not the case, for it had been shown that the foreshores there were composed of mud, sand, and clay. In his view, the theory of the movement, or travel of shingle in deep water was untenable.

It was true, that in all bays, the accumulation of shingle was in the hollow, or deepest part of the indent. Reference had been made to this being the case in the West Bay at Portland. In this indent, the shingle travelled only from the south-west; not a particle of shingle was found along the shore under the cliffs, on the west side of the island of Portland. If the shingle of the Chesil Bank had travelled from the deep water, surely some shingle would be discovered lodging along the shore; but in all the 3 miles, no shingle was to be found. For these reasons he must—until the strongest evidence of an opposite kind were adduced—adhere to the view which he had expressed upwards of ten years since—namely, that the passage of the shingle was along the beach, and not from the deep water towards the shore.

Mr. Peter Bruff said, that there could be no doubt of shingle escaping westward, past Harwich Harbour, because it lay in considerable quantities on the Dovercourt shore, and to the south of Walton-on-the-Naze; in fact, the drainage of a considerable tract of country, the outlet of which was between Walton and Clacton cliffs, had been rendered exceedingly difficult and uncertain, from blockage by shingle. At Walton itself, thirty years ago, there was a fine natural sandy beach, but it gradually disappeared until, some fifteen years back, it left the flat foreshore of London blue clay, locally termed platimore, exposed; but latterly, the beach had been recovered by wooden horses, or groynes, at right angles to the shore, which prevented its travelling southwards. The same observations applied to Dovercourt shore, at the westward entrance of the harbour, where a considerable beach had formed, since Landguard Point overlapped the breakwater. Then, there was a considerable deposit of material called the Pye Sand, just to the northward of Walton Naze, and south-west of Harwich Harbour, composed of various materials, from fine beach, to the finest sand. This deposit stretched about a mile and a half from Walton, in a northerly direction towards Landguard Point. No doubt, the material of which it consisted came from the eastward, was carried past Harwich Harbour, and then forced back to its present position, by the ebbing out of some 2,000 acres of tidal water from the back of Walton, which discharged at Stone Point. It was not the wind, but the waves which drove the shingle; and there was this peculiarity along the coast at Walton, which at first sight appeared singular, if not anomalous, namely, that in a general way, an on-shore wind took the shingle off the

beach, whilst an off-shore wind accumulated it; north-east winds driving the shingle along shore, and south-east winds stripping the beach and laying the shore bare: north-west winds generally accumulated the most beach. Then as to Harwich Harbour, a Government Commission had reported upon it, and many suggestions had been made from time to time for its conservation. He would refer to one, or two points, that had escaped attention in considering the condition of that harbour, and the circumstances which had brought it to its present state. The Naze Point had been referred to as having been subject to great degradation. So recently as 1796, the little village of Walton-le-Soken, with its church, was destroyed by the encroachments of the sea; and since that time, the recession of the land there had been very considerable, in some places amounting to nearly a quarter of a mile. By reference to the Naze Point, it would be seen, that by its recession, Harwich Harbour had been laid open to winds from the south and south-east, which produced very heavy seas, and to that circumstance, he attributed the prolongation of Landguard Point to the westward, more particularly during the last ten years; but its principal advancement had taken place in a southerly direction, from the removal of the stone banks of septaria, which formerly existed to the north of Harwich, at Felixtown, which had allowed the full effects of the north-east gales to fall upon Landguard Beach. He mainly attributed the present condition of Harwich Harbour to these two circumstances—the removal of Felixtown Ledge to the north, and the degradation of the Naze points to the south. It was consistent with his personal observation, that great accumulation had taken place at Landguard Point. There was no doubt also, that at a period not very remote, the waters of the Stour and the Orwel rivers, which at their confluence constituted Harwich Harbour, discharged themselves into the sea at a point much more to the eastward than at present. Landguard Fort was formerly considered as being in Essex, and Silas Taylor, keeper of the King's Store at Harwich in 1676, as quoted by Dale, in his 'Antiquities of Harwich and Dovercourt,' published in 1730, stated that official letters, from the Ordnance Department to the commandant of the fort, were addressed, 'Landguard Fort, in Essex,' though Landguard Fort now appertained to the county of Suffolk. Maps of the date of 1700, showed Landguard Fort as detached from the mainland, and considerably northward of its present site.

The Beacon Cliff, on the west side of Harwich Harbour, had no doubt, been subject to great destruction. Some years ago the government constructed a stone breakwater there, not so much with the object of preserving the point, as of checking and guiding the tides at the entrance of the harbour, and of thus arresting the progress of Landguard Point on the opposite, or eastern side. This

breakwater appeared to have had little or no effect in that way; on the contrary, the prolongation seemed to have gone on much more rapidly than before its erection, and he thought that was reconcilable by reference to its position, and that of Landguard Point, which was to have been operated upon. The tidal wave coming from the northward was, by its momentum, forced past the harbour, from Landguard Point overlaying the breakwater. It then took a reversed direction, before entering the harbour; the course of the tide being, to some extent, influenced by the breakwater. But, as he had already stated, there were about 2,000 acres of estuary, at the back of Walton, in direct position, to receive the tidal wave, the indraught of which, increased with the growth of Landguard Point. These facts, coupled with the injudicious position of the breakwater, would fully explain why the prolongation took place at a more rapid rate than formerly.

There were one or two other localities, to which he would refer. At Aldboro', projects had been brought forward, during the last ten or twelve years, to restore the entrance of the Rivers Ore and Alde to what was assumed to have been its original position, by making a cut through the narrow beach which existed there, with deep water outside and within it. If that project should be carried out, it would be a reproduction, on a small scale, of what Harwich Harbour was a century back. The main object was, to afford refuge to vessels from the northern and Baltic ports, during the prevalence of westerly and south-westerly gales, but not for vessels bound north, for which Harwich was admirably suited. The ancient city of Dunwich was perhaps the most perfect case of obliteration to be found in the kingdom. The only vestige of the city remaining was a dismantled church, on a cliff upon the verge of the sea. From the records left, there was no doubt, that Dunwich had been one of the most populous, and, in a maritime view, one of the most important places on the eastern coast.[1] But what more particularly interested the Institution, was the fact, that an important and flourishing harbour had been in existence, which was now completely lost. The only traces of its maritime position were

[1] Stow, in his Chronicle, as quoted by Gardiner in his 'History of Dunwich, 1754,' thus described it:—"Dunwich, in ancient time, was a City, had brazen gates, fifty-two churches, chapels, religious houses, and hospitals; a king's palace, a bishop's seat, a mayor's mansion, and a mint." Gardiner observes, "Of all its former magnificence, the encroachments of the sea have spared only a few mouldering relics; these, however, are interesting memorials of its fallen greatness. It appears to have been in its most flourishing state during the reign of Henry II. Dunwich rendered one hundred and thirty-three pounds, six shillings, and eightpence aid to marry Maud, the king's daughter, when Ipswich was charged but fifty-three pounds, six shillings, and eightpence. And in the reign of Richard I. Dunwich was fined one thousand and sixty marks, Oxford fifteen, Ipswich two hundred, and Yarmouth two hundred. These sums may afford some idea of the relative importance of those towns, at the periods referred to."—P. B.

to be found at Southwold, some miles to the northward, which harbour was almost constantly choked with shingle. His personal knowledge of the coast did not extend much beyond Yarmouth; but in reference to the origin of the shingle which accumulated to such an extent along the coast between that point and Walton Naze, he might say that he did not know a cliff, or a portion of the coast, that produced shingle to any extent. Throughout that distance, sand and clay cliffs abounded, with bands and boulders of septaria, and deposits of crag and coprolite, but no deposits of angular gravel. It would therefore appear clear that the shingle along this shore was cast up from the sea. Mr. Calver, R.N., and other Admiralty surveyors, tested that question some few years ago, and found, disposed somewhat parallel along the Suffolk coast at a few miles from shore, ridges of shingle corresponding with that on the beach, but more angular. In the intervening spaces between these banks and the shore, casts of the lead commonly brought up sand, and occasionally pebbles. Mr. Calver stated that, "if it had been possible to uncover the bottom of the sea, it would have presented the appearance of a sandy waste with single pebbles scattered over it—travellers, as it were, from the ridge to the shore." Another point of interest was the size of the pebbles on the beach. Where the heaviest sea existed, the largest pebbles were to be found. At Landguard beach the largest shingle might be the size of a sparrow's egg; but at Aldboro', where the sea was heavier, much larger pebbles were cast up. They did not appear to travel along the shore. The finer shingle and sand were carried to Landguard Point, and further southward, but the heavier pebbles remained nearly in the same locality where they were cast ashore.

Mr. John Murray said, that although the Paper was exceedingly instructive, he did not think, the Author had taken a sufficiently extensive view of the engineering features of the harbours along the coast which he had undertaken to describe. With regard to Harwich, about which there had been so much discussion, he had contoured and coloured the Admiralty Chart, published in 1842, from the surveys of Captain Washington. A good notion was thereby obtained of the tracts of deep, and shoal water, in the interior, and the outside, of the harbour. At the junction of the Stour with the Orwell, there was a depth of 5 fathoms, which gradually shoaled outwardly; there were, however, several deep pools along the concave shore on which Landguard Fort was built. At the extremity of the Spit, the channel became very narrow and steep to the eastward. Along the shore, the line of 6 feet under low water suddenly terminated at Landguard Point. On the Essex coast, it ceased at Harwich; but the Cliff Foot rocks formed a shoal, midway between Beacon Cliff and Landguard

Point. The 12 feet contour also ceased at Landguard Point; but on the Essex coast, it extended a long way across the harbour, forming the Altar, Cod, and other banks. The 18 feet contour embraced Wadgate Ledge, and also terminated at Landguard Point. On the harbour side, it embraced the Altar, Cod, and other banks; leaving barely $\frac{1}{8}$th of a mile between it and the low-water mark at Landguard Point. The Cork Ledge was situated nearly 3 miles seaward of Landguard Point; and between the Cork Ledge and Wadgate Ledge there was a depth of $4\frac{1}{2}$ fathoms. Landward of these ledges was the outer anchorage, called the Pitching Ground, separated from the inner anchorage, or Rolling Ground, by a bank, on which there was from $2\frac{1}{2}$ fathoms to 3 fathoms. A fact indicative of the shoaling of this harbour, was, that in the chart of 1842, there was a depth of more than 6 fathoms in the Pitching Ground; but in the chart of 1847, little more than 5 fathoms existed in the same place. In the Rolling Ground, in 1842, there was a depth of 6 fathoms at low-water of spring tides, where, in 1847, there was only a depth of 5 fathoms. Southward of these anchorages, extending landward, were the Ridge, and Halliday Flats, which showed the trail of the shingle, sand, and other matter, from north to south, across the deep-water channel, then carried westward into the bay, and from thence, northward into Harwich Harbour. A breakwater had been thrown out from the cliff point to the 12-feet line; but seaward of that, was a shoal, called Cliff Foot Ledge, or rocks. The Altar bank and Flats, the Cod, Glutton, and other banks, were all formed where deep water formerly existed. The formation of these shoals was a further indication of a gradual choking up of Harwich Harbour, within Landguard Point. The waters of the Stour, and Orwell, no doubt, formerly ran direct to the eastward, along the foot of the cliffs from Walton to Bull's Cliff. Deposits took place at the foot of these cliffs which were embanked and reclaimed. On the seaboard, still greater accumulations of shingle having taken place, caused the marshes to be formed on the inner side, now drained by Walton Creek, into the harbour. Then came the prolongation in a southerly direction of Landguard Point, which overlapped the entrance of the harbour; and, lastly, the gradual shoaling of the estuary, from its non-exposure to the direct action of the sea.

He thought Harwich Harbour, situated on the coast northward of the Thames, deserved particular attention. Government ought to have taken steps long ago to maintain, at all events, if not to improve, such a harbour with deep water inside and outside, as the outlet for the rising commerce of Ipswich. So far as the breakwater had been carried out, it had been of benefit, inasmuch as the shingle was now lying on its southern side; but it ought to

be prolonged to the south-east, as far as the eastern extremity of the Cliff Foot Rocks, which would in a great measure prevent the shingle and fine sand from being carried along with the flood tide into the harbour. To arrest the further progress of the shingle round Landguard Point, he considered that another breakwater should be run out, from its southern extremity, in an easterly direction, following the direction of the Spit. The shingle would then fall into a bay, on its northern side, and as that became filled up, the breakwater would require to be still further prolonged. There would then be no difficulty in obtaining deep water into the harbour from the Rolling Ground, by dredging a channel through the inner deposit, from Landguard Point to the confluence of the rivers Stour and Orwell.

Another place of importance on the east coast was Yarmouth. There were excellent entrances into Yarmouth Roads from the south, and the anchorage was protected, for an extent of seven miles, by the South Scroby, the Middle Scroby, and the North Scroby. Three miles of those sandbanks belonged to the South Scroby, patches of which were dry at low water of spring tides. The Cross Sands, outside the Scroby, had a tract of water between them which had a depth of 18 fathoms, or 20 fathoms. The north-east gales fell first upon the Cross Sands, and passing through the tract of deep water before striking the Scroby Bank, caused Yarmouth Roads to be well sheltered in these gales. As the whole of the coasting trade between the north of England and the Thames passed through Yarmouth Roads, it was important to understand properly its northern entrance, which was somewhat intricate. There was a fair-way buoy at the western end of the Winterton Overfalls, another at the north-east end of the Cockle Sand, with other buoys along its eastern side, and at the north end of the Scroby there was a checkered buoy and a light-vessel, all of which indicated the passage into the Cockle Gateway. This entrance was said to be perfectly safe and accessible by night as well as by day; but he could not think navigation was secure when dependent upon buoys and a light-vessel. He thought, as the entrance was about half a mile in width, and 6 fathoms in depth, it was worthy of serious consideration whether, as this was liable to change, some artificial measures should not be adopted at the end of these banks, so as to maintain a permanent channel into this great thoroughfare for shipping. He thought, the money would not be ill-spent on such a project.

With regard to the travelling of the sands into the Wash, it would be well to detail some of the features of the locality. South of Flamborough Head was the coast of Holderness, which had been long subjected to the undermining action of the sea, and the detritus was carried southward to the Humber. Much of it was

swept into that estuary; but a great part was carried forward into the Wash, and deposited on its northern shore. A considerable quantity was also deposited on the coast of Norfolk, from whence it was drawn, round Hunstanton Point, also into the Wash. Lynn Deeps were maintained by the direct action of the streams of flood and ebb; but the flood tide set over the top of the Ling, and Roger Sands, into Boston Deeps; and on the ebb the water being retained longer therein, its direct course seaward maintained the depth of the channel. Wainfleet Point, and Hunstanton Point, the seaward horns of this great estuary, were, in his opinion, the places where artificial groynes ought to be erected from the landward pointing into the Wash; the former in a southerly direction, the latter towards the west. Under the lee of such groynes, deposits would necessarily take place; and by continuing the system from the sea inwards, large tracts of land might be gained from deposits of sea-sand, which, in time, would become covered with warp. Along the Norfolk coast, there was an expanse of shoal water, extending to the mouth of the Humber, and to the Dogger Bank, in which were interspersed the Silver pits, the Dudgeon, Docking, and other banks. The streams of flood and ebb ran across this extensive shoal, forming off the north-east coast, and parallel to it, the long narrow banks, called Harborough Sand, Hammond's Knoll, and Hewitt Ridges; and, further out, the Leman, Ower, and other dangerous banks.

The towns and harbours of Blakeney and Wells were situated between Cromer and the Wash. Seaward of those harbours were extensive salt marshes, with numerous intersecting creeks, which last were filled, and the former covered, by the tide. Both harbours were therefore maintained, almost exclusively, by the sea water. Many years ago, an attempt was made to enclose the salt marshes of Wells harbour, but evidence was produced to show how detrimental the effects would be upon its depth. As both those harbours must, in course of time, become deteriorated by the shoaling of the sea on that coast, it behoved the authorities not only to prevent any further enclosures, but, as much as possible, to increase the extent of the marshes as a receptacle for tidal water, and he considered, that artificial means ought to be adopted to throw the ebbing waters into the creeks, for the purpose of maintaining them, and of producing a scour at their outfalls.

Mr. W. A. Brooks called attention to a copy of a chart by Captain Collins, Hydrographer to the Admiralty, of the date of 1686, showing the state of Harwich Harbour at that period. The spit, at that time, ran out in a southerly direction. It had since deviated four points to the westward, which had rendered the harbour more difficult of access. Measuring from the centre

of the fort to the end of the spit, on the charts of both periods, it would be seen, that there was scarcely any real elongation of the spit, but merely a change in its position—instead of bearing south from the fort, it was now to the south-west. He was of opinion, that the change in the spit, and thereby the injury to the harbour, had not arisen so much from external, as from internal causes, or, in other words, from changes which had taken place in the Stour and the Orwell. The ebb tides set heavily upon the Suffolk or concave shore of the sea-reach, and were reflected abruptly, and lodged the shingle in the eddy, formed below the point of deflection. He did not think there was any occasion to go so far off as the Naze Point, to account for the alteration that had taken place at Landguard Point.

At the period of Captain Collins' survey, there was much deeper water between Harwich and Landguard Point than at present. Shingle and sand, carried into the harbour by the current and tempestuous waves, were brought down again, by the powerful outset from the Stour waters, and, deflected by Harwich Point, were lodged to the eastward of Harwich. Therefore if it were wished to drive Landguard Spit away, the set of the current of the ebb must be changed, and it should be made to 'debouche' at a tangent to the concave shore, on the north side of the sea-reach, which was the course it took when Captain Collins made his survey. There was also a great change at Handford Water. The Pye Sand had risen and increased in height, and was elongated in a northerly direction. He would throw out the suggestion, whether it was not advisable to augment the tidal power of the effluent water, so as to deepen the entrance into Harwich Harbour, and whether to effect that object it was not desirable to raise and lengthen the Pye Sand by artificial means, so as to lead the body of water from Handford Creek (which was represented as having an area of 2,000 acres), to bring its influence to bear upon the Landguard Point shoal. If that were done, the combined waters of Handford, the Stour, and the Orwell, all setting out in an easterly direction, would carry away Landguard Spit, and thus improve the entrance to Harwich Harbour. He believed the Admiralty break-water had proved of little benefit. It was situated too far away to be of any use in bringing the ebb tide to bear upon Landguard Spit.

Mr. J. S. VALENTINE said that the subject of the travel of the shingle was one of great importance and interest in connection with engineering works upon the coast of England; his personal acquaintance with which, extended from Wells to Lynn, on the north coast of Norfolk. He had been especially engaged in the neighbourhood north and south of Hunstanton. He was called in after the heavy gale of December 21st, 1862, when so much

damage was done, to advise a large landed proprietor in that district as to the best means of protecting his estate from the inroads of the sea. The natural barrier of shingle banks on that part of the coast had been severely breached by the sea, and large tracts of low land had been covered with sea water. At the outset the great difficulty he experienced was to know what had been the action of the sea previously. Being a locality remote from any well-known harbour or large town, no record was to be found of the previous state of the beach. He alluded to this circumstance because it showed the value of the Paper in handing down to posterity the condition of the coast at the present time, and it would be extremely valuable to those who might hereafter be called upon to execute works upon the East coast.

The first question which struck him, in the investigation he had to make, was this—what were the laws which governed the action of the shingle on that coast? He was told, as he had heard it stated in this discussion, that the travel of the shingle was in the direction of the prevailing wind. Upon investigation he found that conclusion was erroneous. He believed the travel of the shingle, along that coast, was not in the direction of the prevailing winds, but was entirely independent of it, and that it was due to the great tidal wave. The prevailing wind was south and south-west, but the travel of the shingle was from the north. If the shingle travelled in the direction of the prevailing wind, it would be found round Hunstanton Point, but from thence eastward to Wells there was scarcely any shingle. Here and there a little was to be found, but there was no accumulation to be compared with the great beds which lay between Hunstanton and the point at Woolverton, spoken of in the Paper as being the place at which the shingle ended. In addition to that, the material of which the shingle was composed proved, that it must have come from the north. He had listened with great interest and attention to what had been said by the Astronomer Royal, as to the shingle being washed up from the bed of the sea. It was impossible that could be the case on the part of the coast of which he was speaking, because the geological formations which lay to the northward for a considerable distance did not contain the stones which were found in these shingle beds. The shingle was composed of chalk-flints, quartz, jasper, agate, and (what, from the direction in which it must have come, was to his mind conclusive) jet. Hunstanton Cliff was the only point along this part of the coast where the geological formations cropped out. The lower portion of that cliff was composed of the lower green sand, above which was a band of red chalk with a large amount of silex in it. Geologists differed as to this band. Some said it represented the gault; others that that formation was entirely wanting, and that it was the true chalk: but,

be that as it might, the chalk which lay above it contained no flint, so that the flint shingle could not have come from that locality. He was therefore convinced that the shingle travelled from the north, that it came from beyond Whitby, and passing round Flamborough Head, collected the flints from the chalk of which that part of the coast was composed. He did not know the coast eastward of Wells, but he was not aware of any point on that coast where there was chalk.

Mr. REDMAN said that the neighbourhood of Mundesley, east of Cromer, and the bottom of the shoal water off Cromer were all chalk.

Mr. VALENTINE thought, that if the shingle came from that neighbourhood, it was probable they would find it travelling from the eastward, before it got round Hunstanton Point; but, if chalk flints were to be met with there, 'in situ,' jasper, and other primary rocks, which were mixed so largely with the shingle, could not have been derived from that locality. He therefore had arrived at the conclusion, that these stones came from the north. Another circumstance tended to corroborate this view: immediately south of the new railway station at Hunstanton there was a gravel bed, which was evidently a raised beach. It resembled in character the beach found at present upon the shore, but it also contained north-country pebbles, and they were mixed with recent shells and fossils, from the older formations of the cliffs to the northward. That, he thought, was a proof that the shingle had been travelling, since a remote period, from the north.

Mr. BROOKS suggested, that a large portion of the shingle might have been ships' ballast.

Mr. VALENTINE said, that could not be the case, as no ships were loaded or unloaded at the locality in question. It was not a coast approached by ships, in fact none came nearer than Lynn. Another circumstance which induced him to think that the accumulation of the shingle was not due to the prevailing winds was—that if there was a moderate wind, for any considerable period, from the south and west, the largest accumulation took place on the north side of the jetties. There was an interesting question with reference to the shingle, which applied not only to this coast but to all others along which it travelled in large quantities, this was—when the shingle got to Woolverton Point, on the Wash, or to Shingle End, near Sandwich, what became of it? Beyond Woolverton, to the south, there was not a pebble as big as a pea. The shingle entirely terminated there. Where did it go to, and what became of it? It had also been asked, whether the land reclaimed from the sea did not exceed the quantity that was lost from the abrasion of the cliffs? He though it did. No doubt, on parts of the east coast the wasting of the

cliffs was very great. At Hunstanton Point, the wasting away of the cliff was going on slowly, but a great extent of land, north and south of that point, had been gained from the sea, which had covered the whole of those levels, at some time or other. Wherever excavations were made, shells similar to those at present existing in the estuary, were found in a very perfect state in the alluvial soil. Immediately north of Hunstanton Point, off the villages of Holme and Brancaster, there appeared to have been considerable loss of land at some remote period; inasmuch as trees, from submarine forests at those places, were washed up during northerly gales, and fragments of turf, or peat, spread in such quantities over the beach off Hunstanton Point as to make it perfectly black. But, on the other hand, the sea was receding from large tracts which it had covered, and artificial enclosures were constantly going on. A large enclosure, containing five or six hundred acres, was made a few years ago by the Earl of Leicester, at Wells: another, of between four and five hundred acres, had lately been made in the parish of Holme; and between Wells and Hunstanton, there were extensive tracts of mud-land and salt-marsh, which were gradually becoming solid land, and which were protected from the sea by the sandhills described in the Paper. He found, that there were sandhills beginning to be formed in some places, outside the old ones, and he therefore thought the probability was, that the quantity of land gained from the sea would much exceed that lost by the action of the sea upon the cliffs.

Mr. Coode, in explanation, said there seemed to be an impression, that he had stated, that the travel of the shingle was in the direction of the prevailing winds. He feared the misapprehension had arisen from his having used the expression 'wind-wave.' But, to show what his views were on that point, he would quote a short passage from his Paper on the Chesil Bank, which was read before the Institution in May, 1853. He then stated: "It has been before observed, that the fact of the largest shingle being found, at what has been called 'to leeward,' is well known in the neighbourhood: this term 'to leeward' must, however, if applied to shingle, be clearly understood as relating to the quarter whence the heaviest seas proceed, and not to the winds."[1]

He agreed in the statement of the Astronomer Royal, that the accumulation of shingle was in the bights of the bays; but that appeared to be almost the only point on which their views coincided on the subject before the Institution. The great point Mr. Coode contended for in his Paper on the Chesil Bank, was, that the travel of the shingle there, was from west to east. Along those beaches, for a distance of about ten miles, there were vast

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xii., p. 536.

accumulations of flint shingle, which could come only from between Lyme and Sidmouth; whilst on the east side of the Chesil Bank, in Weymouth Bay, there was nothing but oolitic shingle, derived from the oolitic rocks of Portland, which were washed by the sea from the Bill; from these rocks, much debris was derived, out of which the oolitic shingle was formed. On the north shore of the same bay, there was nothing but flint shingle. Whence was that derived? Evidently from the chalk formation at Whitenore; so that, in the case of the west side of the Chesil Bank, there were sandstone and flint shingle from Budleigh Salterton, Sidmouth, and Lyme; on the east side of the Chesil Bank, oolite shingle from the cliffs of Portland; and on the north shore of the same bay, there was the flint shingle from the chalk cliff at Whitenore, and west of Lulworth. If the theory advanced by the Astronomer Royal, as to the shingle being torn up from the bottom of the sea, was correct, why was it that there was only flint shingle on the north side of Weymouth Bay, and only the oolite shingle on the south side of the same bay? How was it that the oolite shingle and the chalk shingle were not mixed indiscriminately together on these two beaches in the same bay? To his mind, it was a proof that the shingle was derived from the rocks and cliffs which existed in the outer and more exposed portions of the bay, and that it had been moved from thence, inwards, by the action of the waves.

The Shambles Shoal, immediately in front of Weymouth Bay, was $2\frac{1}{2}$ miles in extent, and $1\frac{1}{4}$ mile wide, measured at the 5 fathoms line, and it stood at a steep slope to within 11 feet of the surface, at low water of spring tides. It had been supposed that that shoal too consisted entirely of shingle, but he had proved that it was composed of nothing but fragments of shells, easily moved, and of the lightest specific gravity. If there were the tearing action at the bottom of the sea which had been alluded to, how did it happen that this shoal, consisting of such light materials, existed there at all, when the surface of it was only 11 feet below low water of spring tides? But the fact was, that the shoal remained in the same condition as it appeared to have been eighty years ago, as was ascertained by comparing the chart made by that accurate surveyor, Murdoch Mackenzie, with one of the best modern surveys. The fact, that this great bank, consisting wholly of fragments of shells, still remained in its position after so long a period, was a sufficient proof, that there was none of that tearing action along the bottom of the sea which had been contended for.

Mr. Redman, in reply, said that he was sure no one could do otherwise than listen with pleasure to the preliminary remarks of the learned Astronomer Royal, but, the deductions which he drew from them were certainly rather startling; knowing the

fact, as Mr. Redman did, which was confirmed by Mr. Coode's Paper on the subject, that the passage of the shingle along the coast on which the Chesil Bank was situated, was from west to east. But the Astronomer Royal argued, from the comparative sizes of the stones, that the passage was from the large stones to the small, or in a westward direction; and he then sought to support that paradoxical position by the extraordinary theory, that the beach did not arise from the degradation of the cliffs westward, but was ploughed up from the bottom of the sea, quoting two examples which Mr. Redman thought bore no analogy to the case—viz., Wexford, in Ireland, and the estuary of the Mersey at Liverpool.

Mr. VIGNOLES said he might be excused for observing, in the absence of the Astronomer Royal, that the learned professor did not contend, that the materials which formed the shingle were not swept away from the beaches from the eastward or westward; but what he maintained was, that they finally come up from the bottom of the sea. A distinction of that character was drawn by the Astronomer Royal.

Mr. REDMAN replied, that attentive and careful study of the hydrographic charts of the locality would show such a position to be entirely untenable. It would be evident by referring to the geological survey of Great Britain, and he was assured by the gentlemen on the staff of that survey, that the exceptional pebbles found to the leeward of Chesil Bank 'in situ' at Lyme, would be at a depth of many hundred feet, opposite the termination of the Chesil Bank. The Astronomer Royal had also raised the same question with reference to the pebbles in the Landguard Promontory. The same origin had been assigned to them, namely, that they had been ploughed up from the bottom of the sea, and that they came from the plastic clay of a character similar to that which existed in Plumstead and Woolwich, underlying the London clay. Now Mr. Redman was assured, that the plastic clay did not crop out in the North Sea at all; and that, with the exception of pebbles from the crag, no other stones were to be found than nodules of septaria, or compressed clay, which owed their origin to the overlying London clay. He might be considered bold in attempting to controvert the opinion of so eminent an authority as the Astronomer Royal, but, having paid great attention to the subject for many years past, and being convinced it was opposed to all observation, he felt compelled to state what he had done.

Attention had been directed to the great degradation of the shores in the estuary of the Thames, particularly along the frontages of the Clacton and Frinton cliffs; and to the action of the land-water drainage and of the sea. To more fully illustrate his

views on these points, he would again refer to the landslip at the Isle of Sheppey, which consisted entirely of London clay. It was 4 acres, or 5 acres in extent, and the entire mass settled down in one night. It was an extension of a former slip, in all, about ten acres; the raised shore formed by that mass of cliff settling bodily down, and pushing the beach and the foreshore before it.

Reference had been made to the changes described to have taken place on the south side of the estuary of the Thames, the deepening of Bullock's Channel, and the shoaling up of the western approaches to Prince's Channel. It was also stated, that the channels of approach to Harwich were generally as deep as were shown on the early maps of Mackenzie. Landguard Point had been described as the termination of the great belt of shingle from the north-east, and it had been stated that no shingle in any quantity was found to the southward of Harwich; but on the other hand, it had been pointed out, that shingle was found to leeward. He would further draw attention to the fact, that though shingle was not found to the westward and southward of Harwich, yet, it was met with again soon after passing the Naze, and that it extended to St. Osyth's; and that the great Holland Sluice passed through a large amount of shingle projected by the drainage waters. With regard to the difference between the forces producing the littoral beaches, and those producing the changes described in the estuary of the Thames, where those light and fluctuating sands almost balanced each other, it had been urged that where a channel deepened on one side, there was a corresponding shoaling on the other side. To this he would say, that he had already pointed out the changes in the shoals. The map by Mackenzie, Spence, and Thomas (1824) showed that Bullock's Channel, then called the 'Smugglers' Swatchway,' or 'Thomas's New Channel,' to the eastward of Prince's Channel, was then 10 feet deeper than the same channel as laid down on the last maps; but that channel was now 10 feet deeper than was indicated by the last charts, so that, there appeared to have been a shoaling since the date of the earliest chart, and subsequently a deepening; which must have been occasioned by considerable oscillation in the channel. The Alexandra Channel was now shoaling, while Bullock's Channel was deepening. The shoaling of the western channel was attributed to the breaking away of the crest of the 'Girdler Sand,' and to the filling up of the western channels, and no doubt, these changes induced a corresponding deepening in the channels to the eastward.

In the Paper, he had described the motion of three great lines of beaches: In the first, from Harwich, to the southward of Lowestoft, the motion was to the southward. In the second, northward at Cromer to the Wells and Blakeney beaches, the general drift

was to the westward; while in the third, from Hunstanton Point along the great belt on the eastern side of the Wash, the general motion was to the southward. There was no doubt these were the resultant motions of these beaches. They were not only affected by the prevailing winds, but the motion was also induced by the particular trend of the coast, and the particular sea to which each coast was exposed.

As allusion had been made to Rye Harbour, he had procured the early Dungeness map from the Museum of Practical Geology, as also the coloured geological sheet of the present day. By marking the distances in a southerly and easterly direction from the Fort, it would be found that the elongation of that point, during a series of years, had been a furlong and a half, and that the mean annual progression was about 8 yards. This was a singular confirmation of the result he arrived at in the Paper which he brought before the Institution some years ago,[1] in which he gave the maximum progression of that point, taking the old charts and surveys by Desmaretz and other early authorities as data, as 8 yards per annum; the progression during the last half century, as shown by this new measurement, having been also at the rate of 8 yards per annum.

He could not coincide in the statement, that no pebbles were found in the London clay cliffs which were described in the Paper. Without exception, all those cliffs along the entire seaboard were covered by masses of the 'Suffolk Crag,' and that crag, consisted of enormous flints, and those flints undoubtedly supplied the major portion of the materials of the beaches to which reference had been made.

It had been alleged, that the deteriorating action at Harwich was rather internal, than external, arising from the shingle travelling backwards and forwards across the channel. To that, he entirely demurred, as contrary to all the facts of the case.

With reference to the beaches south of Hunstanton, it had been argued that the material of which they were formed came from the northward, it being assumed that there was no chalk to the eastward. On this point, he had already directed attention to the fact, that there were extensive masses of crag and chalk, which would supply the materials of those beaches; and the 'Suffolk Crag' was very peculiar in its formation, containing boulders of granite and other exceptional pebbles in its stratification. The shingle would necessarily be highest on the north side of the Hunstanton groynes, when the wind was from the south, or off shore: this in itself was no proof that the shingle came from the northward.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xi., p. 174.

February 2, 1864.

JOHN FOWLER, Vice-President,
in the Chair.

The following Candidates were balloted for, and duly elected :— William Butterton, William Clark, George Johnstone Darley, James Morris Gale, Philip Edward Sewell, Thomas Stevenson, Charles Stone, Henry Vignoles, and John Whitfield, as Members; Charles James Appleby, Thomas Denville Barry, Samuel Bayliss, William Henry Bidder, Arthur Giraud Browning, Edward Antrobus Foden, George Fuller, George Furness, Samuel Gale, Elijah Hoole, Charles Julian Light, Henry Robinson, James Nelson Shoolbred, Edward Pease Smith, Henry Stone, and Robert Harry Inglis Synnot, as Associates.

The discussion upon the Paper, No. 1,103, on "The East Coast of England," was continued throughout the evening, to the exclusion of any other subject.

February 9, 1864.

CHARLES HUTTON GREGORY, Vice-President,
in the Chair.

The discussion upon the Paper, No. 1,103, on "The East Coast of England," was continued throughout the evening, to the exclusion of any other subject.

February 16, 1864.

JOHN ROBINSON M'CLEAN, President,
in the Chair.

No. 1,106.—"The Actual State of the Works on the Mont Cenis Tunnel, and Description of the Machinery employed."[1] By THOMAS SOPWITH, Jun.

THIS tunnel is to be the completing link of the Victor Emmanuel railway, which will put France in direct railway communication with Italy, and place Turin within eighteen hours' journey of Paris. In June, 1863, the railway was opened on the French side to St. Michel, in Savoy, and on the Italian side to Susa, in Piedmont. Modane, near to which is the French, or north entrance to the tunnel, is about 10 miles from St. Michel, on the 'grande route' to Turin. Thence the tunnel will pass under the Col de Frejus, about 18 miles west of the actual Mont Cenis, coming out in Italian territory near Bardonnêche, about 24 miles from Susa. The traffic is at present conveyed from St. Michel to Susa, a distance by road of about 50 miles, by the 'grande route' originally made by the first Napoleon, and known as the Mont Cenis pass, the lowest of the Alpine passes. When the tunnel is finished, it is not unlikely that postal communication and traffic with India may be advantageously transferred from Marseilles to some Italian port. By referring to a map it will be observed, that the line of rail is nearly straight from Paris to Maçon, Culoz, and by the tunnel, to Turin; it afterwards continues by railways already opened, or in course of construction, to Ancona, thence to Brindisi, on the east coast of Italy. A north-west wind prevalent at Marseilles and in the Mediterranean, more particularly during the winter months, makes the entry and 'beating-up' to that port extremely difficult, and sometimes obliges the captains of steamers to abandon the direct line from Malta, and to keep along the coast by the south of Sardinia and France. On the completion of the tunnel, the routes viâ Ancona and Marseilles will compare as follows:—

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[1] The discussion upon this Paper extended over portions of four evenings, but an abstract of the whole is given consecutively.

By Ancona.

	Miles.
London to Turin	1,100
Turin to Ancona	320
Miles by rail	1,420
Ancona to Alexandria, by sea . . .	1,260
	2,680

By Marseilles.

London to Marseilles, by rail . . .	736
Marseilles to Alexandria, by sea . .	1,743
	2,479

Taking thirty miles an hour as the average speed on railways, and ten miles an hour by sea, the journey by the former route will occupy one hundred and seventy-three hours, as compared with one hundred and ninety-eight hours viâ Marseilles, or a saving of twenty-five hours.

The advantages that might be expected to arise, from the establishment of railway communication between Italy and the rest of Europe, have not been underrated; and Italian Engineers have, for more than twenty years, considered various projects for overcoming the natural difficulties which intercepted it. Of the proposed routes, that selected seemed to be the most feasible; and, indeed, it was only a question whether the mountain should be crossed by a series of inclines, with engines specially adapted to them,[1] or whether a tunnel should be constructed.

In 1857, MM. Sommeiller, Grandis, and Grattoni, engineers, who had already surveyed the line of railway now adopted, and who were then engaged upon other works in which compressed air was employed, brought before public notice a plan for using it to drive machinery for replacing the ordinary method of boring by hand-labour. Experiments, at the expense of the Italian Government, were made near Genoa with machines on this principle, and with compressed air as a motive power. These were so satisfactory that a Commission was appointed to examine how far these machines were applicable to the proposed tunnel, as well as to ascertain if there was sufficient water-power for compressing the amount of air necessary for working them. An abundant water supply having been found to exist at each end of the pro-

[1] *Vide* "De la Traversée des Alpes par un Chemin de Fer." Par E. Flachat. Tract 8vo. [vol. cxxvii.] Neuilly, 1859.

posed tunnel, and the report being otherwise favourable, the project was accepted, and, pending the construction and erection of the machinery, a commencement was made, at both ends, by ordinary mining, in the beginning of the year 1858. A careful examination of the geological features of the district showed that no particular difficulties were to be apprehended in the rocks to be pierced by the tunnel, these being, for the most part, micaceous and talcose schists, traversed by strings and veins of lime and quartz. It was predicted that a bed of quartz, 100 mètres thick, might be encountered near the north end; but, so far as can be judged, the 'forehead' is already in advance of the place where it should have occurred; so it is to be hoped that some change of inclination diverts it altogether from the line of the tunnel. The ordinary difficulties of making a tunnel $7\frac{5}{8}$ miles in length are in this case much increased, on account of the impracticability of sinking shafts on the line to ventilate it; and its progress must necessarily be slow for the same reason, only two points of attack, the ends, being available. Without being sanguine that, by the aid of machinery, the time which would be required to make it by ordinary means could be greatly reduced, the work would perhaps never have been undertaken, as, judging from the usual rate of progress in such cases, it must have required from thirty to forty years to complete it. It was feared, and urged as an objection, that the ventilation before the tunnel was finished would be so imperfect as to prevent, or at least materially to retard, its construction. The Author never entertained any apprehensions on that account, as the ventilating air-current in many coal-mines passes over a longer distance, and far exceeds in quantity any possible requirement at Mont Cenis; and by the introduction either of a horizontal or a vertical brattice, the tunnel may be placed under the same conditions as many parts of a coal-mine. It would have been almost impossible to employ any other power than compressed air for working the machines in the 'forehead,' which affords, after its escape, a supply of fresh air to the workmen, and by expanding from a greatly reduced bulk to its former volume, and consequent absorption of heat, the temperature, when the men are at work, is considerably reduced, seldom exceeding 70° Fahr. It is also readily applicable for general purposes, and small engines for pumping, &c., are driven by it. Gas, made at the surface, is used for lighting the tunnel at the Bardonnêche end, and is introduced by pipes up to the 'forehead.'

The tunnel, on leaving Modane, is of the following dimensions: 25 feet $3\frac{1}{2}$ inches wide at the base, 26 feet $2\frac{3}{4}$ inches wide at the broadest part, and 24 feet $7\frac{1}{4}$ inches in height, the arch being a semicircle nearly. At Bardonnêche the height is increased $11\frac{3}{4}$ inches, and the arch is made elliptical, to resist the greater strain

caused by a different inclination of the strata. The exact length between the ends is 7·5932 miles, or 7 miles, 4 furlongs, 7 chains, 9 yards. The present ends will not, however, be the actual entrances when the tunnel is finished. To avoid sharp curves, the line will leave the tunnel about 415 yards from the Modane end, and 273 yards from that at Bardonnêche (Plate 3, Fig. 3). The tunnel at Modane is built entirely with stone; at Bardonnêche the side walls only are of stone, the arch, with the exception of 327 yards at the beginning, being of brick. The northern entrance, at Modane, is at an elevation of 3,945 feet, and the southern entrance, at Bardonnêche, of 4,379 feet, above the sea. There is a difference in level therefore of 434 feet between the ends. On this account the tunnel will leave Modane with a rise of 22·20 per 1,000, or about 1 in 45½, and will continue so for one-half its length, when it should attain the elevation of the rails from Bardonnêche, which are to have a rise towards the middle of 0·50 per 1,000, or 1 in 2,000 only. The highest point on the surface in the line of section is 9,525 feet above the level of the sea. When once the work is completed, it is expected that there will be a constant draught from the north to the south, as the latter is not only higher, and the air more rarefied, but it is exposed in a greater degree to the heat of the sun.

Before proceeding to state the rates of progress made by the ordinary means, and those obtained since the introduction of the machinery, the Author will give a brief description of the system of tunnelling pursued at Mont Cenis, as a general idea of this system is indispensable for the appreciation of the statements which will shortly be made; and he will reserve for subsequent consideration more detailed notices of the machines employed. The establishment at each end of the tunnel consists of machinery for compressing the air, workshops for making and repairing machinery, offices, storehouses, residences for the engineers, barracks for the workmen, forges, &c. At Modane the entrance is about 328 feet above the bottom of the valley, up which the railway passes, and where the workshops are placed. The railway, to gain this elevation, makes a 'détour' up the valley. The entrance is, however, in direct communication with the shops, by an inclined plane, with two lines of rails, worked by a water-balance, the inclination being about 30°.

Experiments and attempts have already been made, both in England and in America, with a view to introduce machinery for tunnelling, but never with complete success. In England a machine introduced by Captain Penrice, R.E., was made and tried near Newcastle-upon-Tyne, and was afterwards used by the Ebbw Vale Iron Company. It was intended to bore a gallery about 4½ feet in diameter, by means of a frame with six radiating arms, or

ribs, furnished with cutters fixed on a shaft worked direct from a steam cylinder, making as many as one hundred strokes, or blows, per minute. By this system the whole of the material extracted would be in the form of chippings and coarse grains, and in thus reducing it to so small a size, much unnecessary work would be performed. Any means of tunnelling by machinery, in which the power afforded by the expansion of gunpowder is not made available, must fail to be economical. M. Sommeiller's system has the great advantage of using it. His object has been to apply machinery to bore small holes to receive the charges of gunpowder, and to do this in less time than can be accomplished by hand labour. This has been effected by mechanism of very ingenious construction, composed of two distinct machines. One is a fixed rotary engine, and its duty is to work the valve of the larger cylinder, to advance or withdraw the latter on its frame as may be required by the increasing depth of the hole, or to allow of the borer being replaced, and, finally, to give a rotary motion to the borer itself. The other machine comprises a larger cylinder for propelling the tool, or borer, against the rock, the tool or borer being a direct continuation of the piston-rod. The piston-rod is large, and a constant pressure is kept on the annular surface of the piston, to return it after each propulsion, without the use of a valve with double action. The air for driving these machines is at about 5 atmospheres above atmospheric pressure, and each machine makes two hundred and fifty strokes per minute. The pressure on the piston in striking, deducting that required to overcome the constant pressure on the other side, is 216 lbs. Calculated by the pressure of the air, and the number of feet travelled by the piston per minute, each of these machines is of $2\frac{4}{10}$ H. P.; presuming, as the Author believes to be the case, that the compressed air is not used expansively, or cut off before the end of the stroke. The length of the stroke may be varied from 2 inches to $7\frac{1}{2}$ inches, and the diameter of the cylinder is $2\frac{1}{2}$ inches. Each of these machines weighs about 6 cwt. A stock of the machines is kept on hand to replace those that are injured. The work is so severe that, although simplified as much as possible, the machines are still liable to frequent derangement. On an average, after eight or ten 'shifts,' or, say, after boring from sixty to eighty holes, a machine needs repacking, and perhaps the replacing of some working part. It may not perhaps be too much to say, that four machines must be kept in reserve for one that is working. The cost of each machine is about £80. A strong iron frame, weighing with the apparatus it carries 15 tons, provided with levers, crossbars, adjusting screws, &c., moves on rails close to the 'forehead,' and on it are fixed the machines. Each machine can be made to work at almost any inclination; but as, in doing so, it is likely to interrupt

the efficient working of the others, the holes may practically be considered as being bored nearly horizontal, an increased number making up for any loss on account of their not being so well placed as they might have been. This is not so great a disadvantage as it may appear at first sight. Miners consider it of great importance that the holes should be so situated as, when exploded, to lead to the disruption of the largest quantity of matter. It is, however, of equal importance at Mont Cenis, that the rock brought away should not be in large pieces, as a longer time would then be required to remove them, and possibly, in some cases, the pieces might have to be again broken up by blasting. The frame carries at Modane eleven machines, and at Bardonnêche nine machines. The size of the advanced gallery is about 10 feet square; but an experiment is being made with a gallery of 7 feet square, in which case the necessarily smaller frame can only carry seven machines. If this is successful the system will be much more practicable, and will be an important consideration for mining proprietors; as the original size of 10 feet square, if indispensable to the efficiency of the machines, is too great for ordinary mining galleries. Behind the frame there is a truck, bearing wrought-iron vessels filled with water, which is kept at a pressure of about 5 atmospheres, by being in communication with the compressed air, and is used for the jets, one to each machine, which keep the tools cool, and remove the borings. The air is conveyed along the tunnel in pipes about $7\frac{5}{8}$ inches in diameter. Some distance from the 'forehead' a caoutchouc pipe conveys it to a small reservoir on the hinder part of the frame, from which it is taken by caoutchouc pipes, about 2 inches in diameter, to each machine.

Each time of working, or 'shift,' about eighty holes are bored. When these are completed, the frame and machines are withdrawn, and another set of men charges and fires them, again relieved by others, who remove the rock shot down. The division of time amongst them is very variable. It may, however, be assumed as from

6	to 8	hours for	the machinists,
$1\frac{1}{2}$	to 2	„ „	charging and firing,
3	to 5	„ „	removing 'déblais,'

or hardly two complete 'shifts' every twenty-four hours. In June, 1863, during twenty-seven working days, forty-six 'shifts' were worked; except, as in June, when there was a fête more than usually popular amongst the workmen, and when the works were suspended for three days, for the Fête d'Italie, the works are continued day and night, without interruption, Sundays included. An alignment is made once in three months, from an observatory at each end. As yet no error has been detected.

The frame is provided with an engine, worked by compressed air, for advancing it into, and withdrawing it from, the 'forehead.' At the completion of a 'shift' it is withdrawn from 60 yards to 100 yards, to the shelter of some doors, removed from time to time as the 'forehead' progresses. When it is again required, it can be taken to the 'forehead' in two or three minutes; owing to the length of borers used, 6 feet is quite near enough, and once there, little time is required for setting the machines to work; within five minutes, two or three perhaps are in operation, and in ten minutes nearly all. Three or four large holes $3\frac{1}{2}$ inches in diameter, are bored about the middle of the 'forehead;' the remainder are about $1\frac{3}{16}$ inch diameter and 2 feet 8 inches to 3 feet deep. The larger holes are the same depth, but are not charged, their purpose being to ease the others only, and to increase the effect of their explosion. The holes round these larger ones are the first charged and fired, making a cavity in the middle, or 'laying in' as it is called by miners. The remainder are exploded in turn from the cavity outwards. The workmen—Piedmontese for the most part—are hardy and courageous under circumstances which require more than ordinary perseverance. An inducement to work is given in a premium upon more than a certain advancement per day in the advanced gallery. The distance on which the premium is based varies with the nature of the rock. The standard is now 1 mètre per day.

For	$1\frac{1}{10}$ mètres		$1\frac{1}{10}$ day's wages	are paid
,,	$1\frac{1}{5}$	,,	$1\frac{1}{5}$,,	,,
,,	$1\frac{3}{10}$	,,	$1\frac{3}{10}$,,	,,
,,	$1\frac{4}{10}$ and above,		$1\frac{1}{2}$,,	,,

This is reckoned and is subject to adjustment every fortnight.

For removing the 'déblais' produced by explosion, there are two lines of rails at Modane, one on each side of the line which carries the support and the machines. It is removed in small wagons to the end of the advanced gallery, is there tipped into larger wagons, and is thence taken by horses outside the tunnel.

The removal of the products of explosion is very well organized, and could only be improved by a system of removing *en masse*, which would be difficult to carry out. It may be possible, however, to construct an iron frame running on wheels, to be placed at the 'forehead' at the time of explosion, which would receive the greater part of the products of explosion, and this is now under consideration. Much time would be saved if such a system were practicable.

Before giving some data as to the number of men employed, the progress, &c., a few words must be said about the machinery for

compressing the air. Water is the motive power for this purpose, and a system of applying it has been adopted by M. Sommeiller, which though novel, is expensive in construction and erection, and not very effective. A canal, about 2 miles long, brings the water at Bardonnêche to a height of 85 feet above the level of the machines. At each end there are ten machines of the kind about to be described. Each machine communicates by a pipe, 24 inches in diameter, with the reservoir of water above, as also with a wrought-iron vessel, of boiler shape, and about 610 cubic feet capacity, one being attached to each machine. The air is compressed up to 5 atmospheres above atmospheric pressure. This operation is performed as follows (Plate 4, Fig. 1). Suppose the pressure valve A to be shut, the exhaust valve at B to have already performed the work of the preceding stroke, and also to be shut, and the water standing in the column Z up to the level H O; the space between A and the column being full of water, and that from the level of H O up to the valve C full of air, admitted by the clack valves *d d*, when the water escapes by the opening of B. By the turning of a cam on the shaft G, the valve is free to fall; its own weight is assisted by the pressure of air at 5 atmospheres upon the piston of a small cylinder, F, placed above. The water then rushes up the column, compressing the air contained in it, and forcing it through the valve C into the reservoir. C is placed at such an elevation on the column Z, as to prevent the water following the air into D, but not so high as to leave a portion of air at the end of each stroke, which would re-expand to its former bulk; which in each case would occasion a loss of power. The valve A being closed, by means of the further turning of the cam, B is in turn opened by another cam on the same shaft, and the water sinks to the level H O, whilst the column becomes refilled with air. The exhaust valve being closed, the action is repeated, $2\frac{1}{2}$ strokes to 3 strokes per minute being the working rate of each machine. The cams for the ten machines are worked by a compressed air engine of 8 horse-power.

The compressed air introduced into the reservoirs is kept at a constant pressure of 5 atmospheres by a water pipe from a reservoir with that pressure. A pipe $7\frac{5}{8}$ inches diameter conveys the air from the reservoir to the tunnel. The joints of this pipe are very tight, being turned and a caoutchouc ring compressed in each. The pipes rest on rollers, carried on stone pillars, and expansion joints are introduced occasionally outside the tunnel, where the temperature is variable.

This system of compressing air (à coup de belier) is also established at Modane; but there was a further difficulty at that place, in not having water available at a sufficient pressure, although there was an abundant supply at a lower level. M. Sommeiller

therefore carried out the singular idea of using the same machines as at Bardonnêche, to avoid the additional cost of constructing others of different dimensions, although in doing so he was obliged to erect a large cistern, near the machine house, 85 feet above the machines, as at the other end of the tunnel, and pump the water into it, for effecting the compressure, by means of water wheels, at a greatly increased cost of construction, complication of machinery, and loss of power—the more to be regretted as a subsequent introduction of pumps for compressing the air, worked direct from water-wheels, gave better results and were cheaper.

The system last introduced at Modane, consists of a horizontal pump, with a vertical branch at each end, worked by connecting rods from the cranks of a water wheel; two such pumps being worked by each wheel. The pump is $21\frac{1}{2}$ inches diameter, and the stroke 5 feet long. Each makes 12 strokes per minute, and each is capable of sending more air into the reservoirs than one of the other more complicated machines, and with a less expenditure of power. The piston is surrounded by water, which rises with each stroke of the piston, in the two vertical branches alternately; the variation of pressure, or resistance against the wheel, is very considerable, increasing, of course, towards the end of each stroke; a heavy fly-wheel is therefore placed inside each water wheel. This system is obviously to be preferred to the other, in any application of machinery to be used for compressing air.

Such being a general description of the machinery, both for compressing air and for applying it to the advancement of the tunnel, the remainder of this Paper will be confined to statements of, and considerations on, the progress actually made, and to be expected, in comparison with that already made, under nearly similar circumstances, by hand labour,—the probable duration of the works, —the number of workmen employed,—and the principal points of an agreement made between France and Italy, on the acquisition of Savoy by the former country, when nearly half the section of the tunnel became French territory; but the Italian Government undertook the responsibility of finishing the whole of the works.

The Author has twice had the privilege of visiting the works on the Mont Cenis. The first time was in the autumn of 1860; the second was in July of 1863. At the date of his first visit, machines had not been applied at either end. The machinery was first applied at Bardonnêche, in the beginning of 1861, and at Modane on the 25th of January, 1863. As before stated, the tunnel was commenced by ordinary means in the beginning of 1858.

The following are the rates of progress in the advanced gallery:—

MODANE.

Hand labour.[1] From 1858, to end of 1862, 5 years, 1·655 feet per day.

Machine.[2] From January 25th, 1863, to June 30th, 1863, 156 days, but 153 working days only, advancement of 171·25 mètres = 1·119 mètres, or 3·686 feet per day.

BARDONNÊCHE.

Hand labour. From 1858 to end of 1860, 3 years, driving 724 mètres = ·6612 mètre, or 2·148 feet per day.

On the introduction of machines in 1861, but little progress was made, owing to the breakage of compressing machinery (170 mètres about). In 1862 there was an advancement of 380 mètres = 1·040 mètre per day, or 3·411 feet per day.

The following notes of advance at Modane were copied from the shift book of the Mining Engineer, in which every detail relating to the progress made, is entered and afterwards tabulated :—

		Advancement per Month.	Total length of Advanced Gallery completed.	
1863 January	25th	. .	921	mètres.
„ „	31st (6 days)	4·43	925·43	„
„ Feb.	28th (28 „)	23·31	948·74	„
„ March	31st (31 „)	34·44	983·18	„
„ April	30th (30 „)	31·42	1,014·60	„
„ May	31st (31 „)	38·80	1,053·40	„
„ June	30th (27 „)	38·85	1,092·25	„

January and February apart, when the men were unaccustomed to the new work, it seems that the rate of progress was 1·206 mètre, or 3·953 feet per day, and taking June alone, 1·439 mètre, or 4·719 feet per day. In June there were 46 shifts; the mean progress per shift, must then have been ·8445 mètre, or 2·769 feet. Comparing the progress made from 1858 to 1863 by hand labour (·5047 mètre per day), with that obtained during the entire time the machinery has worked (1·119 mètre per day), the latter is in the proportion of 2·217 : 1. Or, what is fairer, considering the disadvantages the machines laboured under before the workmen were disciplined in their use, taking the progress in January

[1] Referring to previous notes, the Author finds it mentioned, that at the date of his first visit to Modane, twelve miners were constantly engaged in driving the advanced gallery; there were three sets, each working eight hours; at Bardonnêche twenty miners per shift were so employed.

[2] The progress at Modane, since the introduction of machinery, seems better than at the other end: it must be remembered, that it was only applied there two years after its introduction at Bardonnêche, where the first and greatest difficulties consequent to applying new machines were to be contended with.

and February apart, 1·206 mètre per day; the proportion is 2·389 : 1, and taking June only, 1·439 mètre per day 2·851 : 1, or nearly 3 to 1 at Modane.[1]

The above progress was, both in the case of machine and manual labour in a gallery 10 feet square, 11 machines being employed, of an aggregate force of 26½ H.P., estimated by the ordinary rule applied to steam engines.

PROBABLE DURATION OF WORK.—June 30th, 1863.

1,092·25	mètres had been pierced at Modane	
1,450·00	„ „	Bardonnêche
2,542·25	„ in all	
9,677·75	„ yet to complete	
12,220·00	mètres.—Total length of tunnel.	

Assuming the progress to be as in June last, at the rate of 1·439 mètre at each end, 9 years 2½ months will be required from June 30th, 1863. In view, however, of the greater facility with which the machines will be worked when the men are more habituated to them, and of better results when their power is increased, as is now proposed, and their construction and application simplified, although quite aware of the increased difficulties to contend with as the 'forehead' advances, the Author thinks it probable that an advance of 2 mètres per day will shortly be made at each end. A great delay is now caused by the length of time required to remove the 'déblais.' If indeed a system were introduced for removing the 'déblais' *en masse*, instead of by small wagons, then 60 shifts might be worked per month, and 2 mètres would be a moderate estimate. That rate at each end would require 6 years 7 months only, compared with 26 years 3 months at the rate (·5047 mètre per day) made at Modane before machinery was introduced.[2]

The advanced gallery is enlarged to full tunnel size, and walled by ordinary means. A conduit is made between the two lines of rail, for drainage.

[1] In making these calculations three days are subtracted in June, in which the works were suspended during the Fête d'Italie. No allowance is, however, made for delays for repairing machinery, or air-pipes, during which the works have been suspended for a few hours occasionally.

[2] At Bardonnêche, in 1862, 380 mètres were driven, and the following are some statistics relating to their execution, given before the Italian parliament:—582 shifts were worked, of an average length of 7 h. 39 min. for machines, and 6 h. 2 min. for exploding and removing 'deblais;' 18,622 kilogrammes (20 tons 9 cwt. at 2,000 lbs. per ton) of gunpowder were used; 47,751 holes were bored, from 30 to 32 inches deep, averaging 78·6 per shift. 76,000 mètres (47 miles) of fuse were used.

Any favourable judgment on the results obtained at the Mont Cenis must be modified by the consideration of the enormous cost of establishing and working the present system at that place, as well as the large number of workmen required. Of the cost of the establishment it would be difficult to make even an approximate estimate. The machinery was nearly all made at Seraing, near Liége.

The expense of applying M. Sommeiller's system depends, necessarily, very much on local conditions. And although ignorant, as he has already said, of the cost of establishing and working it at Mont Cenis, the Author will endeavour to institute a rough comparison, between the cost of boring any large tunnel by machinery and by hand labour. In this he is greatly assisted, by having been able to obtain some information about the number of men employed under the present system, which he believes to be reliable. As first in importance the men in the tunnel will be enumerated. In the advanced gallery at Modane, the machinists work a shift of from 6 to 8 hours, and are relieved by the chargers, who in turn are replaced by men to remove the 'déblais.' A second set of machinists follows the latter, but the same chargers and labourers serve, their work not lasting long. There are therefore 2 sets of machinists, 1 set of chargers, and 1 set of labourers. The machinists for 2 shifts amount to 88, or 44 per shift. The chargers to 9 per set. The labourers for removing the 'déblais' to 30, making a total of 127 in the advanced gallery.[1]

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[1] The following details were supplied to the Author by the mining Engineer in charge at Modane, and show how this number of 127 is made up, and the rate of wages paid to each man :—

MACHINISTS per two shifts—

2 foremen, at 7 francs per day.
10 adjusters, 1 to each 2 machines, for fixing, withdrawing and making small repairs, at 5 francs per day.
20 miners, to guide and change tools, at 2 francs 60 cents. to 2 francs 90 cents. per day.
20 labourers, at 2 francs to 2½ francs.
22 labourers, 1 for the hinder end of each machine, to open and shut valves, as directed by the miner at the head of the machine, and stop or set to work the machine, at 2 francs to 2½ francs.
10 boys, to oil machinery, at 1½ franc.
2 mechanics, for attaching the pressure pipes to the machines, at 2½ francs.
2 boys, for oil lamps.

88, or 44 per shift.

CHARGERS—

6 miners, at 4·20 francs per 2 shifts.
3 boys, at 1½ francs per 2 shifts.

REMOVING DÉBLAIS—

1 foreman, at 4 francs per 2 shifts.
2 miners, to bring down loose pieces, &c., at 4 francs per 2 shifts.
27 labourers, at 2 francs to 2½ francs.

30

For enlarging the tunnel there are three sets of miners per 24 hours, and two sets of masons, all working 8 hour shifts, in number amounting to 344, which added to 127 previously enumerated, makes a total of 471 employed underground. There are, however, stone-dressers, quarry-men, blacksmiths and labourers at the surface to be taken into account, increasing the number at the tunnel and entrance to 700. The establishment below, workshops, machinery, canals, &c. afford employment to about 240, and at the time of the Author's visit, as indeed nearly always, from 150 to 200 were employed as "occasional:" total for Modane 1,140. The number was rather greater at Bardonnêche, from 1,200 to 1,400 being generally employed, giving a total of 2,540.

In making a comparison of the cost of driving an advanced gallery by machinery, and by hand labour, a judgment must not be altogether based upon the works and the results at Mont Cenis. There is no doubt that establishing, as M. Sommeiller has done, on so large a scale, an entirely new system, without experience in its use and application, many expenses have been incurred, that would be avoided hereafter.

The following comparison will therefore be general to any work on a sufficiently large scale to justify the adoption of machinery, rather than special to the Mont Cenis. The data are insufficient to enable the calculation to be made with accuracy, but it will be based on statements already made. It will be confined to mining charges only, *i.e.*, labour, tools, gunpowder, and candles. Removing the 'déblais' is common to both; as is also enlarging and walling the tunnel, and timbering the advanced gallery. The rate of progress of the gallery at Modane which is 10 feet square, will be taken into consideration; but the Author feels certain, that in a 7-feet gallery, the machines would compare with hand labour to better advantage. Previous to the introduction of machinery the miners drove, on an average, 1·655 foot per day; 36 men in 3 shifts of 12 men each being employed. This advancement would then cost—

36 miners at 2*s.* 6*d.*	£4 10 0
Tools, gunpowder, and light	1 10 0
Cost per day and per advancement of 1·655 foot	£6 0 0

or £10 17*s.* per yard.

It is hardly necessary that the Author should allude to the small portion of the total cost, of either advanced gallery or tunnel, expressed by "mining charge." To compare, in like manner, the cost of driving the same gallery by machinery, it will be necessary to take—

1. The cost of motive power for compressing the air to drive the perforators.

2. The working charges of shops to repair the machinery, in excess of what would be required if no boring machines were used.

3. Men employed: mechanics, blacksmiths, &c. in such shops; as also engineers and stokers, and those to attend to air-pipes, water supply, engine for pumping water, &c.

4. Men employed during the machine shift.

5. Wear and tear of machinery, and many other incidental expenses, which, in a fair comparison, would require full and careful consideration, and would vary according to local conditions.

The points on which this comparison is based are stated, to show how the proportional cost has been arrived at: the Author has only made it, in the hope that the attention of the members of the Institution may be drawn to its better consideration. As water power could only be obtained in exceptional cases, steam will be assumed as the motive power for compressing the air used for driving the boring machines. At the rate of driving practised last June, a mean progress of 2·769 feet per shift was made. The labour of miners and machinists would amount to £4 14*s.* 8*d.* per shift, and, say, £3 10*s.* for gunpowder, tools, and light, amounting to £8 4*s.* 8*d.* per shift and advancement of 2·769 feet, or £8 18*s.* 4*d.* per yard. Eleven machines were used, expending in compressed air a power of 26½ horses at the end of the gallery. Each machine, however, requires a motive power in the system of compressing applied at Bardonnêche of 8 H.P.; but as they are not working continually, a constant power of 40 horses would be sufficient to supply them. Assuming that the motive power was steam, and that 4 tons of coal per day were consumed, at 10*s.* per ton, say £2, and the wages of engineers and stokers cost 15*s.* per day, there would then be for cost of motive power, per day £2 15 0

About 240 men are now employed in the shops and about the machinery at Modane, say, this was reduced to 120, at 3*s.* per day	18 0 0
And calculate for steam power to drive machinery, &c. for coal and attendance per day	1 10 0
Wear and tear on machinery, say 20 per cent. on £20,000, say per day	5 10 0
Cost per day and per advancement of 4·719 feet . .	£27 15 0

Or £17 12*s.* 9*d.* per yard at the rate accomplished in June, 1863, which, added to the mining charge of £8 18*s.* 4*d.*, would amount to £26 11*s.* 1*d.* per yard, as compared with £10 17*s.* by hand labour. From which it appears, so far as may be judged

from so rough an estimate, that by machinery a progress three times as fast as by hand labour may be effected, but at two and a half times the cost. For mining charges, in the case of a gallery for mining purposes, the comparison might stop there; but not so in the case of a railway tunnel. For the enlarging, timbering, walling, and general charges are quantities common to both, and the proportion will be notably diminished when they are added. The estimated cost of making the Mont Cenis tunnel was £120 per mètre. It makes but little difference, therefore, whether the mining charge there is £10 or £26 per yard. The ultimate proportion of cost to put against an increased advancement of three to one would thus, instead of being two and a half to one, not exceed £126 to £110, assuming the charges common to both systems to amount to £100 per yard, which, in the case of the Mont Cenis tunnel, they will not fail to do. In ordinary cases, to which the preceding comparisons are supposed to refer, rather than to the Mont Cenis, say in the case of a tunnel costing £30 per yard, which is perhaps not too much to assume for a tunnel of sufficient length to make it advisable to apply machinery, the comparison would naturally be more disadvantageous than in the Mont Cenis, where the general charges are so exceptionally high. Say, therefore, in the case of a tunnel to cost £30 per yard when completed, that £5 per yard was for mining charge in the advanced gallery, and £25 per yard for general charges. By applying machinery, the mining charge would be increased to £13 per yard; and the £25 per yard for general charges might be increased to £27 per yard, as air-pipes would not be required if machinery were not introduced; the proportion of cost would then stand as 40 : 30, which would not purchase at all dearly an advancement in the proportion of 3 to 1.

Although not prepared to go into an estimate, with any pretensions to accuracy, of the cost of establishing works on the scale assumed in the preceding comparison, the Author would mention £20,000 as the result of a rough calculation. He must again repeat, that this estimate does not refer to the Mont Cenis in particular. The improvements recently introduced, and the better results lately obtained, point to the conclusion, that an increased rate of progress may be looked for. M. Sommeiller has proposed several alterations, by which it is hoped to increase the actual rate of $1\frac{1}{2}$ mètre to 3 mètres at each end per day, with a less cost per yard than is now incurred, as the work will be done in the same time, and with nearly the same amount of labour. If these hopes are realized, an increase of six times the speed might be attained, without seriously increasing the cost. At such an average rate from June 30, 1863, the work would be completed in four years and eight months and a half.

Without entering into calculations as to the amount of air required by any given number of men, and for the dilution of noxious gases arising from the combustion of gunpowder, it may be stated that the exhaust air from the perforators is adequate to the requirements of the advanced gallery. The greatest number of men employed there at one time is during the machine shift, when there are 44. During the charging and removing of the 'déblais' a jet of air is left open near the forehead. Each machine uses about 8 cubic feet per minute of compressed air = 48 cubic feet at atmospheric pressure, and if eight machines are working together on an average throughout the shift, there will be a supply of 384 cubic feet per minute. But though in the advanced gallery the ventilation is sufficient, it is not so in the large gallery, as the miners and labourers, 250 mètres from the forehead, have been working for some time past in an extremely vitiated atmosphere, at a high temperature; and it is evident that a more efficient means of ventilation is required. Ample power is available for compressing air at the surface, and it could always be used as a means of supplying fresh air to any part of the tunnel; but the waste of power would be such as no engineer would be inclined to sanction. Therefore separate means are being adopted, of the efficacy of which until the completion of the tunnel, no doubt can be entertained. The tunnel is to be divided horizontally by a brattice slightly arched. The upper section is about 75 square feet, and communicates with a chimney (by means of a brick conduit), placed 200 feet up the mountain side, near the entrance. The brattice at Bardonnêche is formed of planks, covered with 3 inches of soil, well beaten. The present draught is very strong, but the brattice is only finished for about one half the distance. If the natural draught should not be strong enough when the forehead advances, a furnace will be placed in the chimney. The air enters the tunnel on the underside of the brattice, passes up the entire length, and returns by the upper part.

To show the circumstances under which the works are being prosecuted, the following translation is given, of the principal heads, omitting details, of an agreement entered into between France and Italy, on May 7th, 1862:—

"1. The expenses arising from the construction of the railway between Modane and Susa, shall be borne by the two Governments, each for the part situated in its territory.

"2. The French Government will undertake the completion of the works between Modane and the entrance to the Mont Cenis tunnel, and the Italian Government those on the part between the outlet of the same and Susa.

"3. The tunnel shall be made under the charge and at the expense of the Italian Government. The cost of the part between

the middle of the tunnel and the mouth of the same, at the Bardonnêche side, shall be entirely at its charge; that of the part between the entrance at Modane and the middle of the tunnel shall be at the charge of the French Government—the original frontier being retained in a political point of view.[1]

"4. The amount to be paid by the French Government for the making of that part of the tunnel situated in its territory, is fixed at seven hundred and sixty thousand pounds (£760,000), in case the duration of the works should not exceed twenty-five (25) years, from the first of January, eighteen hundred and sixty-two (January 1st, 1862).

"In case of the works being completely finished before the expiration of twenty-five years, the capital of seven hundred and sixty thousand pounds (£760,000) will be increased by a premium of twenty thousand pounds (£20,000) for each entire year by which the maximum of twenty-five years shall be reduced. In case the works are completed in less than fifteen years, the premium will be raised to £24,000 for each year by which that term is reduced.

"5. The capital stipulated in the preceding article will only be paid by the French Government on the completion of all the works of the tunnel—the double way included—and when the section from Modane to Susa shall be opened for traffic.

"During the execution of the works, interest at the rate of five per cent. (5 per cent.) upon the cost of that part completely finished, shall be paid annually to the Italian Government. To this effect, and that the interest may be paid on the mean advancement of each year, a measurement[2] shall be made by both parties on the 1st of July each year, to ascertain the length of gallery finished on the French side. To this length the price of one hundred and twenty pounds per mètre (£120) will be applied, so that the sum of seven hundred and sixty thousand pounds (£760,000) stipulated in Art. 4 cannot in any case be exceeded. Interest on the sum thus obtained shall be paid on the 15th of January of the following year.

"The first measurement shall be taken on the first of July, eighteen hundred and sixty-two (1st July, 1862), and the payment of the first year's interest shall be made on the fifteenth of January, eighteen hundred and sixty-three (15th January, 1863).

"The works must be so conducted, that the length of gallery finished on the Italian side shall never be less by more than one hundred mètres (100 mètres) than that finished at the same time on the French side.

"6. If the works of the Mont Cenis tunnel are not completely finished on the first of January eighteen hundred and eighty-

[1] "Toute réserve étant d'ailleurs faite pour ce qui concerne de la limitation de la frontière au point de vue politique."

[2] "Un mésurage sera fait contradictoirement."

seven (1887), the French Government shall be exonerated from the payment of the cost of constructing the part situated in its territory, and the interest will cease. As also if, before that time, the Italian Government shall decline the continuation of the works, in fault of a declaration on its part to that effect, the works shall be considered as abandoned, if at the end of any year the total length of gallery finished does not show a mean advancement of at least two hundred and fifty mètres (250 mètres), a year from January 1st, 1862, on each side, French and Italian.

"7. The sum of eight hundred thousand pounds (£800,000) that the Victor Emmanuel Railway Company is to pay as subvention according to Article 16 of the agreement[1] will be divided as follows:—Five hundred and twenty thousand pounds (£520,000) to Italy, and two hundred and eighty thousand pounds (£280,000) to France.

"On the completion of the works, the French Government shall be put in possession of all lands acquired, and all works executed, in its territory by the Italian Government—such as underground galleries, lines of rail, weirs, canals, reservoirs in masonry, and buildings.

"The grounds, buildings, and works unconnected with the tunnel shall be given up in the state in which they may be.

"The Italian Government reserves to itself the right of taking the machines, tools, and movables which may be in the buildings, as well as materials and stores."

Supposing the works to be finished at the expiration of ten years, from January 1st, 1862, and that the length of gallery completed at the end of the first year is 800 mètres, with an addition of 590 metres each succeeding year, then, at £120 per metre, the simple interest paid by the French Government will have amounted, according to Article 5, to £207,200. The sums received by the Italian Government, according to Articles 5 and 7, for the execution of the works will then be—from France—

Price as per Article 4	£760,000
10 years' premium at £20,000, per Art. 4	200,000
5 years' premium at £24,000, per Art. 4	120,000
Interest received during the ten years, per Art. 5	207,200
	£1,287,200
Adding the sum, per Article 7, to be paid by the Victor Emmanuel Railway Company	520,000
Total . .	£1,807,000

[1] "Cahier des charges."

The estimated cost of completing the tunnel is £2,600,000; so that, taking into account the value of machinery left on their hands, if the above estimate be true, and the works are brought to a close in ten years, the Italian Government will not have to buy the advantages of a railway into their territory very dear. It would appear, also, that the French Government would pay for that part of the tunnel situated in their property the sum of £1,287,200, which divided by 6,110 mètres (half the length of the tunnel) gives £210 as the rate per mètre.

Such are, in outline, the general observations the Author has been able to make upon an engineering work, which in magnitude is inferior perhaps to one only (Isthmus of Suez) in execution at the present day. He has been induced to prepare this communication, because he considers the attention of Engineers in this country has not been sufficiently drawn, either to the work, as a whole, or to the ingenious machinery used for its prosecution. Already, with the short experience that has been gained in its use, the results are sufficiently satisfactory to show, that the system contains the elements of success—success which can only be developed and perfected like all the great inventions of the past and present age—by the untiring perseverance of those whose interest or ambition it is to devote themselves to its accomplishment, and by continually encountering and overcoming the many and great difficulties which oppose it. Attention must and will be drawn to it; for with the enterprise of this age, the necessity will be felt of improving the present system of tunneling. That necessity rightly felt, the means will not be long in following.

Description of the Machinery in use.

Having explained the actual state and prospects of the works at the Mont Cenis tunnel, and the circumstances under which they are being prosecuted, it only remains for the Author to describe more in detail the nature of the machinery used.

The machines in the forehead of the tunnel, called perforators, to distinguish them from the other machines, are driven by the power of compressed air. The machines for compressing air are of two classes, one on the principle of the hydraulic ram, where the water, by its momentum, compresses a given quantity of air at each stroke, without the intervention of machinery further than valves for the admission and escape of the water; the other, in action like a common force-pump, is worked from an overshot water-wheel. At the present time the former kind is exclusively used at Bardonnêche, the Italian end, and the latter at Modane, the French end of the tunnel: at a future period both will be used at each end. Water, of which there is an abundant supply, is available at Bardonnêche with a head of $85\frac{1}{4}$ feet, and is used, with that pressure direct, in the machines on

the hydraulic ram principle; but at Modane the available head is about 20 feet only, and water can be raised, by four overshot wheels, to a cistern 85¼ feet above the level of the exhaust, as at Bardonnêche, so that machines identical with those in use there can be applied. Ten such compressors are erected at each end of the tunnel.

The pump compressors at Modane are worked direct by two water-wheels, each working two pumps. These pumps are on a better principle, and compress the same quantity of air with less expenditure of power, than those on the hydraulic ram principle, even when the latter are applied, as at Bardonnêche, under the most favourable circumstances; but they were not introduced till after the latter had been erected at both places.

With both machines the air is compressed to 5 atmospheres above atmospheric pressure. Plate 4, Fig. 1, is a section of a "compresseur à coup de belier" (hydraulic ram).

X is the supply pipe of cast iron, 2·04 feet diameter, connecting the machine with the reservoir.

A is the pressure valve, opened and shut by the cam *a*, fixed on a shaft worked by an engine of 8 H. P., two such engines being used, one for each five compressors.

B is the exhaust valve, worked by the cam *b* on the same shaft as *a*.

C is a valve for admitting the compressed air to

D, a wrought-iron vessel, or reservoir, of about 610 cubic feet capacity, one being attached to each machine.

E is a water pipe from a reservoir, about 170 feet above the machine, keeping the air in D at a constant pressure of 5 atmospheres.

F is a small cylinder with a piston on the valve rod of A, on which a constant pressure of compressed air is acting, to cause the pressure valve to fall quickly.

G is a shaft, on which the cams are fixed for working A and B; it is driven by a compressed air-engine.

d d d, clack valves for the admission of air into

Z, a vertical column in which the compression takes place.

H O, exhaust level.

The valve A is a movable hollow brass cylinder, about the same diameter as the supply pipe, and works vertically in a copper-lined cylinder attached by feathers to the outer case; by the fall of A communication is opened between the reservoir and the machine. It is essential that this fall should be rapid, so that, in the unmasking of the ports, no resistance may be made to the inflowing water; for this reason the cylinder F is applied. The total pressure on the piston is 1,470 lbs., and this, added to the weight of the valve and rod, causes it to fall quickly. A ring of

caoutchouc, 2 inches thick, receives the shock, but it becomes crumbled after a time under the effects of these repeated blows, and requires to be frequently replaced. Reedy filaments in the water are more pernicious than sand or mud, clogging the valves, and impeding their free action. Filters are consequently placed in the reservoir above, to prevent the entrance of such obstructions into the machine, and at the bottom of the valve-chest, A, is a small hole, *c*, always open to prevent the accumulation of sediment.

B, the exhaust valve is, like A, a hollow cylinder working vertically in a copper-lined cylinder, the reverse of A, opening or unmasking the exhaust ports during its upstroke: a caoutchouc ring receives it when it falls, as in A.

The relative and alternate opening of the two valves is effected by the shape and position of two cams on the shaft G. At Bardonnêche a safety catch was in use, which would not allow A to fall before B was shut, but this has not been introduced in the machines more recently constructed at Modane. C is a conical valve with vertical guides.

If the valve A were to open slowly, and so gradually allow the water to pass through A into Z, the air in the latter would offer a gradually increasing resistance, until it was compressed to such tension as to balance the pressure due to $85\frac{1}{4}$ feet, minus the height to which the water rose before such an equilibrium was established, and be far short of the 5 atmospheres which it is intended to have, before it can lift the valve C and pass into D.

The distance from H O to C is 14·1 feet, the air in Z, before the introduction of water, would be at simple atmospheric pressure equal to a column of water 32 feet in height, and the pressure of inflowing water would be that due to $85\frac{1}{4}$ feet + the atmospheric pressure.

Let x = height above H O, to which the water would rise before being counterbalanced by the compressed air between its surface and the valve C, its position can then be ascertained by the formula

$$\frac{14{\cdot}1}{14{\cdot}1 - x} = \frac{85\frac{1}{4} + 34 - x}{34}, \text{ whence } x = 9{\cdot}723.$$

Its mere standing pressure is, therefore, far from sufficient to compress the air to the required tension, leaving a space of 4·377 feet full of air, which space should be occupied at the end of each stroke by water only.

The valve A is, however, so arranged as to open quickly, and the water has an unimpeded circulation through it. The only resistance it has to contend with is that of the atmosphere on the surface of the water, at the level H O in the column Z; it rushes up the column Z, carrying the air, which constantly diminishes in bulk before it, with increasing velocity, until it reaches the point x ascertained by the preceding formula, whence it proceeds by its

own momentum, but more and more slowly, until it comes to rest at C, after forcing the volume of compressed air through that valve. It is of the greatest importance to the efficiency of the machine, that the valve C should be at a proper elevation; by being too low a quantity of water is allowed to pass through, amounting to so much waste of power, or by being at a height which the water with its momentum cannot attain, it leaves a portion of air at each stroke, which, not only causes a loss of power, but in expanding to its former bulk acts prejudicially to the machine, by giving to the exhaust water a greater pressure than it should have. Any small quantity of water passing through C is caught at *e*, where there is a small gauge and cock for exhausting it. At each stroke of the machine a quantity of air is compressed equal to the contents of the column Z, from H O to C, and as each makes $2\frac{1}{2}$ to 3 strokes per minute, the quantity of compressed air per minute furnished by each (at 5 atmospheres above atmospheric pressure) should be

$$\frac{\cdot 7854\,(2\cdot 04)^2 \times 14\cdot 1 \times 2\frac{1}{2}}{6} = 19\cdot 2 \text{ cubic feet,}$$

and the expenditure of power in the water used to produce this effect would be

$$\frac{62\frac{1}{4} \times \cdot 7854\,(2\cdot 04)^2 \times 14\cdot 1 \times 2\frac{1}{2} \times 85\frac{1}{4}}{33{,}000} = 18\frac{1}{2} \text{ H. P.}$$

Allowing for waste at the valves and at the aperture C, this may be called 20 H. P. at least. It would seem, therefore, that each cubic foot of compressed air at 5 atmospheres, in the reservoir D, represents an expenditure of about 1 H. P. in the machine.

This is not positively correct, but to arrive at any near approximation of the power expended and the quantity of air compressed would be extremely difficult; indeed, elements must be considered that could not be correctly judged without actual experiments and comparison of the results, such, for instance, as the development of heat during compression, the absorption of air by the water, loss of power in lifting the valve C, an obstruction, slight as it is, which causes the air at one time to reach a pressure of 6 atmospheres above atmospheric pressure, power required to work the valves, friction, waste, &c.

Such experiments have not been made, and therefore the "effet utile" of the machine will yet remain for some time unknown. The effect of the whole of the preceding hindrances is to increase the amount of H. P. expended compared to the amount of air compressed. The valves of the machines are worked by cams driven by an engine of 8 H. P., worked by compressed air, and it is not at once obvious how the primary motion is to be imparted when the reservoirs are empty, and no compressed air is obtainable

to work the cams. In such a case the water pressure E is allowed to act, and by filling up the space occupied by the air in the reservoir D, it reduces the latter to the required tension, and affords a sufficient supply to put the engine in action.

M. Sommeiller intends to increase the pressure of the compressed air to 6 atmospheres above atmospheric pressure. This will make a notable difference in the effect of the latter, a large proportion of the present power being taken up in overcoming the friction in the perforators, and the inertia of the mass to be propelled against the rock.

At Modane, although a head of about 20 feet only is at present available, an almost unlimited supply of water may be obtained; and although machines identical with those at Bardonnêche have been erected, another description of machine for compressing the air has proved decidedly superior, and will probably be found the most effectual means of obtaining that medium. The Author was unable to procure a drawing of one of these machines, but a pump, nearly identical with those at Modane, will serve to illustrate their construction. (Plate 4, Fig 2.) It is in use at Seraing for preliminary experiments on the perforators made there for the works at the Mont Cenis. For this description he is indebted to M. Devillez, of Mons, the Author of a valuable treatise[1] on compressed air as applied to mining purposes.

A is the pump, lined with copper, with a stroke of $3\frac{1}{2}$ feet to 5 feet, the length being varied by altering the position of the crank-pin.

B, the vertical columns in which water rises or falls alternately, according to the motion of the piston in A, which is always surrounded by and working in water.

C, valve for the admission of air, always covered with water.

D, valve through which the compressed air finds its way to the reservoir, also covered with water to keep it cool and prevent vibration.

T N, conducts the air to the reservoir.

Q, cistern, into which the water which passes through the pressure valve with the air, as sometimes happens, is forced: it has two cocks, from which a constant supply of water falls upon the valves C and D, and keeps them always covered.

K is a spherical cast-iron vessel, terminating in a small cylinder containing a valve, *p*, which opens or closes communication between the cistern, Q, and K. A hollow copper ball, O, filled with compressed air to resist the external pressure, floats, and is connected by a small rod with *p*; when the water rises too high it opens *p*.

[1] *Vide* "Des travaux de percement du tunnel sous les Alpes, et de l'emploi des machines dans l'intérieur des mines." Par A. Devillez. 8vo. Plates. Bruxelles, 1863.

In Plate 4, Fig. 2, the piston is shown about the middle of its stroke, advancing towards the left; compressed air is being forced from the vertical column B, whilst air is entering the other, and filling up the vacuum left by the receding water. In setting the machine to work, a sufficient, or rather more than sufficient quantity of water is introduced through the valves C; if too much water be introduced the machine soon rights itself, as the surplus will pass through the valves D, fall into K, and by the rising of O, and consequent opening of the valve *p*, be forced, by the pressure in K, through a small pipe, into the cistern. This action would be repeated so long as there was surplus water in either column. A small quantity is always passing, for more or less water enters by the valves C, at each aspiration; this is not of sufficient amount to be detrimental to the machine, but serves to keep the water cool and to supply what is absorbed by the air. At Modane the springs, *c c*, are replaced by levers with a counterweight, the springs not being sufficiently delicate for admitting air at a low pressure. It is well known that in many attempts to introduce compressed air, as a motive power, in England and France, the heating of the working parts was so great as to be a hindrance to its successful application, and special means had to be taken, by surrounding these parts with cold running water, to absorb the heat. At the Mont Cenis, neither during the period of compression, nor afterwards in the application of the air, is any material increase of heat manifest. The immunity M. Sommeiller's system enjoys in this respect is doubtless owing to the constant presence of water, and to the air becoming saturated with watery vapour, whilst all the working parts are moistened at each stroke. The water is constantly changing in the pump compressor, but only to a certain extent, while in the other machines, "à coup de belier," it changes completely. The Author would not have it inferred from this, that no heat is developed in compressing the air by the machines above described; the heat is developed as in other systems, but is absorbed by, and passes off with, the water. The part which becomes heated is the valve C, on the column Z, which is not overrun by water as the other parts are; but although the heat is as great as the hands can bear, it does not extend more than 4 feet or 5 feet down the pipe between it and the reservoir.

The chief points of interest about the air-pipes from the reservoir to the forehead of the tunnel are, to know the loss of power in conveying air under a high pressure, and at a considerable velocity, over a long distance, and also the amount of leakage which takes place, under these circumstances: for a loss, with so subtle a fluid as air, can not be avoided. Both have been proved to be inconsiderable. Judging from experiments made by Pied-

montese Engineers no great loss will take place even when it is necessary to carry the air 6,500 mètres, or more than half the length of the tunnel. At Bardonnêche it was found, with a pressure in the reservoir of 4·70 atmospheres, that the pressure at the forehead, after being conveyed 1,624 mètres through a pipe $7\frac{5}{8}$ inches in diameter, and afterwards through a small pipe to the reservoir on the frame which carries the machines, was only reduced to 4·5 atmospheres, whilst eight machines were actually working and expending collectively 64 cubic feet of air per minute. To ascertain the leakage, the reservoirs were filled, as also the pipes from them to the forehead of the tunnel, the machines were stopped, and the equalizing pressure of water shut off from the reservoir; at the end of twelve hours, it was found that the pressure had only diminished from 5 atmospheres to 4·8 atmospheres.

The pipes are of cast iron, about $7\frac{5}{8}$ inches in diameter, with turned faces, and a groove at each joint, in which a caoutchouc ring is tightly compressed (Plate 4). Between the compressors and the mouth of the tunnel they are supported by stone pillars; expansion joints, also of iron, and very simple and effective, are introduced occasionally. Caoutchouc tubes were tried unsuccessfully. The small loss which takes place under a considerable pressure, 75 lbs. per square inch, is a testimony of the efficiency of the supply pipes and joints now used.

The perforators are shown in Plate 4^a, in which A is the larger, or boring cylinder, its piston having a variable course.

a is the piston rod.

b, continuation of the above, to which is attached, by a turned joint and key, the borer C.

B is a small rotary engine, whose duty is to give the borer a slight turn at each stroke, to advance and withdraw the cylinder A, and to work the valve of the latter.

C C, two guides connected together by curved pieces, forming the frame of the machine, on which A rests, supported by two shoulders on each side. On the iron frame are supports adapted for carrying the greater part of the weight of the frame and machine, but they are further fixed at the end.[1]

On the lower sides of these guides C are ratches, about 1 inch or

[1] Formerly the support was reversed, each guide carrying a projecting pin, which rested as in a cup in the fixed supports; this manner of fixing was not so ready and convenient as the present one, in which an alteration of a few inches longitudinally can be made with ease, where the original method would entail considerable work, in moving the levers and supports of the truck, or frame, which carries the perforators.—T. S.

$1\frac{1}{4}$ inch in length. They are also cut, for a certain portion of their length, with a square thread in which the screw D can work. This screw is attached to the cylinder A, but is free to revolve independently, and so advance, or withdraw the boring cylinder.

d, supply pipe to A and B, with a telescope joint to adapt it to the varying length.

e, a jet for injecting water into the hole when it is being bored.

A machine to perform the operation of boring, as practised by miners, must be able to perform the following duties:—1. to give a sudden and violent blow with the borer, and to withdraw the same after each stroke; 2. to advance as the hole increases in depth; 3. to withdraw, or get rid of the borings; 4. to turn the borer slightly on its axis at each stroke, so that it may not strike twice on the same place. The easiest way of describing the action of the machine will be, perhaps, to follow its course as it performs each separate duty.

The percussion and return of the boring tool are thus accomplished: the small engine B works, by a pair of pinions, a square shaft *f*, on the longitudinal axis of the machine, on which are fixed a toothed wheel *g*, a ratchet and eccentric *h*, and a cam *i*. F is the valve of the larger cylinder; *j* the valve rod, which is kept, by the pressure of the air on its inner surface, in continual contact with the cam *i*. The surface of the cam resembles the thread of a screw; at each revolution it advances the valve, its pitch being equal to the distance the valve should travel, and suddenly releases the valve rod. The number of strokes of the boring cylinder is therefore dependent on the speed at which the small engine B is worked.

Assume the piston in the position represented in Plate 4^a, the pressure port has just been opened, and a pressure of (say at the end of the tunnel) 4·6 atmospheres, or 69 lbs. per square inch, is acting upon the surface of the piston in a cylinder $2\frac{1}{2}$ inches diameter on the opposite side of the piston. There is, however, the resistance of a constant pressure acting on the annular space; the difference of the area of the piston rod and of the piston, which reduces the area on which the pressure is effective to that of the piston rod, or 3·14 square inches (2 inches diameter). The shaft *l* in the interior of the piston does not diminish the effect, as the pressure is effective in the hollow space; a pressure then of (3·14 × 69) 217 lbs. is forcing the piston forward. In order that the piston may never strike against the front end of the cylinder, as it might do with considerable force by the breaking of a boring tool, the aperture in which the constant pressure is admitted to the cylinder is so placed, that it would be shut by the piston before reaching the end. The piston then would have a cushion of air before it, for which there would be no escape, and which would prevent it

striking the front end; in like manner, as it shuts the exhaust port on its return, and meets the pressure of the air, it cannot strike the other end of the cylinder. The piston and gland are packed with leather. The rotation of the cam causes the valve to advance and close the pressure port, opening at the same time the exhaust port. On its further rotation the valve-rod is released, and the valve assumes the position shown in Plate 4[a]. At each revolution of the cam, then, the piston, piston-rod, and boring tool are suddenly urged forward and again withdrawn, and the first and most important duty of the machine is performed.

The rotation of the boring tool is effected as follows:—on the square shaft *f* the eccentric *h* works on to a ratchet wheel *h'* on the shaft *l*. The latter being square and fitting into the piston, on turning, turns also the piston and boring tool; *h'* has sixteen teeth and each revolution of the eccentric causes it, and therefore the boring tool, to turn $\frac{1}{16}$ on its axis; this is effected during the return stroke of the piston.[1] The ratchet wheel *h'* is furnished with a break, to prevent it turning by its own momentum, when struck and passing over more than one tooth.

The advance and the withdrawal of the machine may be thus described:—Resting upon the teeth on the under side of the guides C is a fork *q*, with two branches *q'*, which are kept pressed against the ratchets by a spring. Upon the piston rod *a*, there is a buffer *n* for striking a stop *x*, upon *q;* this stop can be altered, and the length of the stroke of the machine regulated by it. The fork is connected by a rod *r*, with a clutch H, keyed on the same shaft as the ratchet *h'*. The clutch H fits into D; and, when they are in gearing, the latter of course turns with the ratchet wheel and the shaft *l*. When the cylinder A is not required to advance, H and D are disconnected. The stop is placed on *q*, in such a manner that when the piston has attained the full limit of stroke which is desirable, the buffer shall strike against it and depress it, as well as the branches *q'q'*. The latter are thus disengaged from the teeth on C, and advance one degree—being pushed by the spring K; another spring presses *qq* against the teeth, and prevents them passing over more than one at a time. The fork *q* is thus pushed forward, and with it the clutch H, which is put into connection with D. H, it will be remembered, turns $\frac{1}{16}$ on its axis, with each stroke of the machine. D then begins to turn; worms itself forward by the teeth in the inside of the guides C, and forces the cylinder forward, the boring

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[1] In some of the later machines, the shaft *f* is prolonged the length of the guides, and the eccentric, *h*, is placed at the end of the frame, *h'* being under it; this is to avoid torsion, the distance between the eccentric, where it is here shown, and the boring tool being considerable. It is not known whether this will be adopted permanently; if it possesses an advantage in one respect, by being more in the centre of the mass to be turned, it is not so convenient for advancing the cylinder as the present arrangement, as will afterwards be described.—T. S.

tool working all the time as before. The cylinder is now advancing, but the fork q, and with it the clutch H, are stationary. D moves forward with the cylinder, and gradually disengages itself from the connection, when the cylinder again becomes stationary, until by the hole deepening the length of one of the teeth, it is again put in connection and motion as before. The length of stroke is least as the cylinder comes to rest, and greatest at the moment of lifting the fork, but the irregularity is trifling. When it is required to withdraw the machine, the air is shut off from the larger cylinder, the ratchet between h and h' is disconnected, a toothed wheel g is slipped along and put in gearing with y, the fork is raised, by which H and D are put in gearing, and the small engine being set to work, the screw D is made to revolve, and by working on the teeth inside the guides C C, soon withdraws the larger, or boring cylinder. This can also be done without using the small engine, the fly-wheel of which is furnished with a handle, so that hand power may be applied.

For withdrawing the borings, as before stated, a strong jet of water plays on the hole whilst the machine is at work. The pipe e is in some of the later machines soldered inside one of the guides C, and is less in the way than in its present position. Many changes in detail are constantly being introduced. The Author has endeavoured to describe that most in use at the time of his visit (July, 1863), although some important modifications were about to be introduced. The small engine B has been successively tried, with an inclined cylinder and two pinions, with a vertical cylinder working direct on the square shaft f, and with that shown in the present illustration. In place of the spring G an arrangement has been lately tried, by which a ram, or plunger, acted on by the compressed air, works in the valve-chest opposite the valve-rod, and pushes forward the catches $q'q'$, when disengaged by the strokes of the buffer on the piston.

The nominal power exerted by each machine, and the amount of power required to supply it with compressed air, can be readily ascertained, when the pressure acting on the piston, and the number and length of strokes per minute are known.

The dimensions are—

Diameter of piston of larger engine.	$2\frac{1}{2}$ inches.
Area of ditto	4·9087 in.
Stroke 6 to 8 inches, say . .	7 inch = ·58 ft.
Volume of air consumed per stroke .	34·36 in.
Diameter of piston of small engine .	2·375 in.
Area of piston	4·429 in.
Stroke 2·375 in., say for double stroke	4·750 in. = ·395 ft.
Volume of air consumed per double stroke	21·037 in.

Following the ordinary rule, the larger cylinder should perform the work of

$$\frac{4{\cdot}9087 \times 69 \times {\cdot}58 \times 250}{33{,}000} = 1{\cdot}488 \text{ H. P.},$$

and the smaller one

$$\frac{4{\cdot}429 \times 69 \times {\cdot}395 \times 250}{33{,}000} = {\cdot}914 \text{ H. P.}$$

Together 2·402 H. P.[1]

In the larger cylinder, of the 1·488 H.P. expended, ·955 H.P. would be exerted in pushing the piston forward, and ·533 H.P. in returning it.

Taking, however, the quantity of compressed air consumed, it will be found that 34·36 cubic inches are consumed at each stroke in the larger cylinder, and 21·037 cubic inches in the smaller cylinder, together 55·397 cubic inches per stroke. $\frac{55{\cdot}397 \times 250}{1728} = 8{\cdot}026$ cubic feet per minute, and it will be remembered, that in considering the compressors, it was stated approximately, that each cubic foot of air when compressed to 5 atmospheres, represented an expenditure of 1 H.P. So that for each machine proposed to be employed in advancing the progress of the tunnel, compressing machinery to the extent of at least 8 H.P. must be provided, supposing the compressed air is not used expansively in the perforators, and air at 5 atmospheres above atmospheric pressure is used. This proportion would not be so unfavourable, if either the air were used at a lower pressure, or if it were used expansively in the cylinders of the perforators. The Author considers the latter is quite compatible with the nature of the work, and the force of the blow to be given by the piston rod in the striking cylinder.

The communication is accompanied by a series of diagrams, from which Plates 3, 4, and 4[a] have been compiled.

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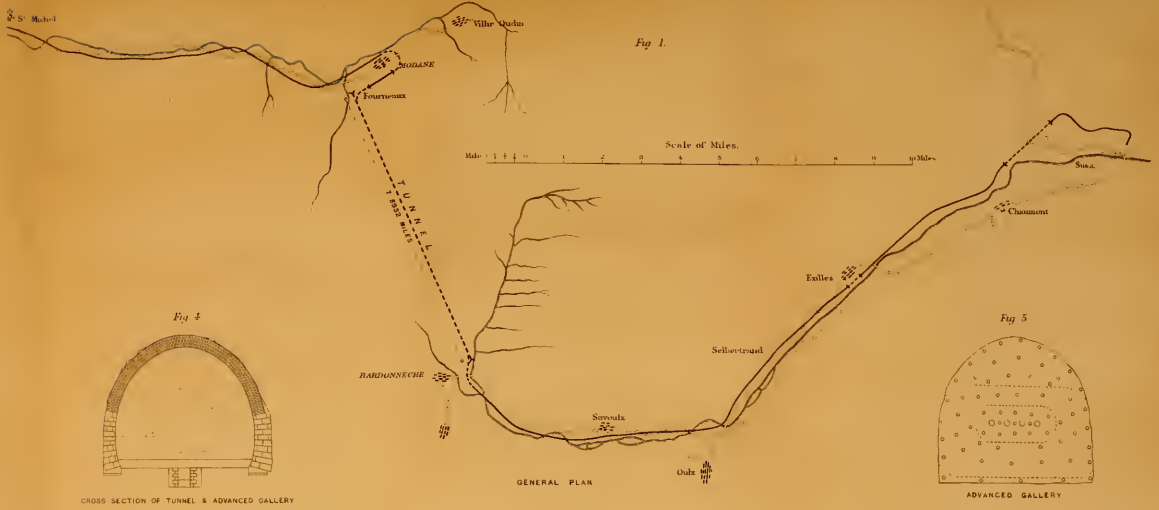
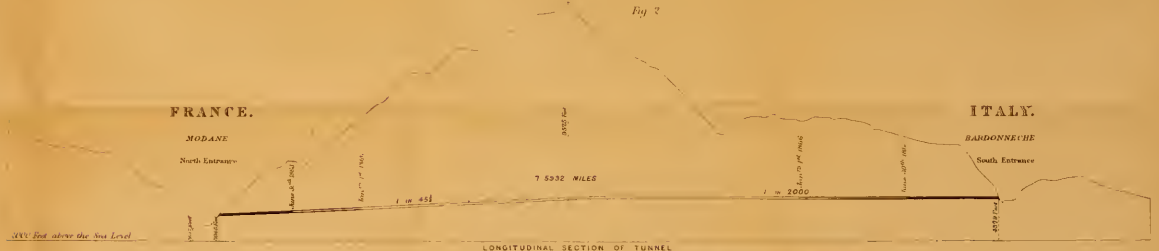
[1] Of the 2·402 H. P. only a part is effective, for it is found, that with a pressure of 3½ atmospheres the machine, though in motion at nearly full speed, possesses no greater effective power than is required to bore one inch, or less than one inch in an hour.

MONT CENIS TUNNEL.





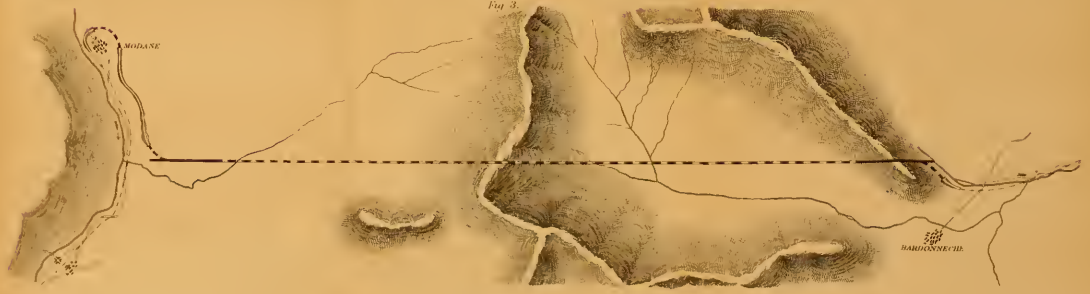


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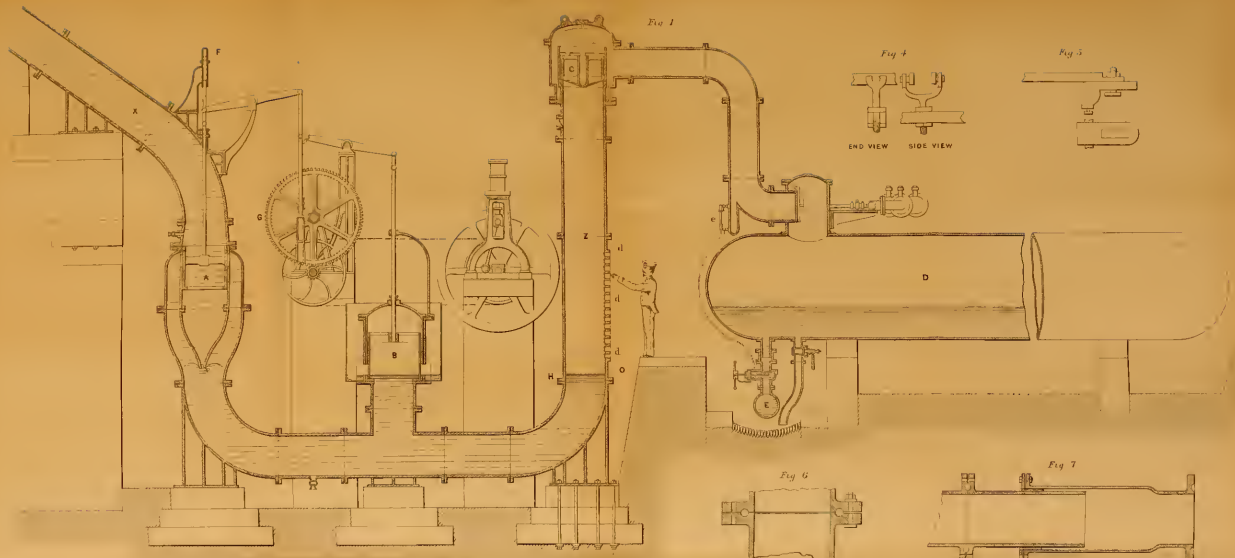
Fig 1



COMPRESSEUR A COUP DE BELIER (HYDRAULIC RAM)

Fig 4

END VIEW SIDE VIEW

Fig 5

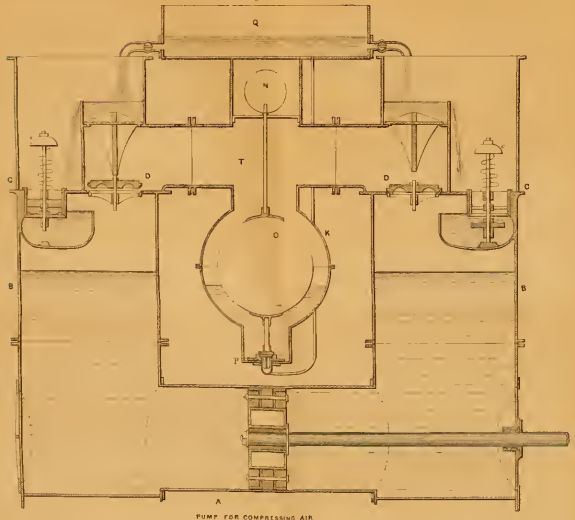
Fig 6

ORDINARY JOINT

Fig 7

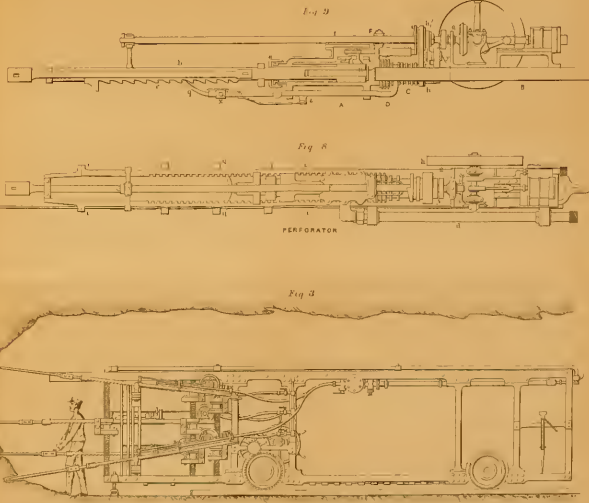
EXPANSION JOINT

Fig 2



PUMP FOR COMPRESSING AIR

Fig 3



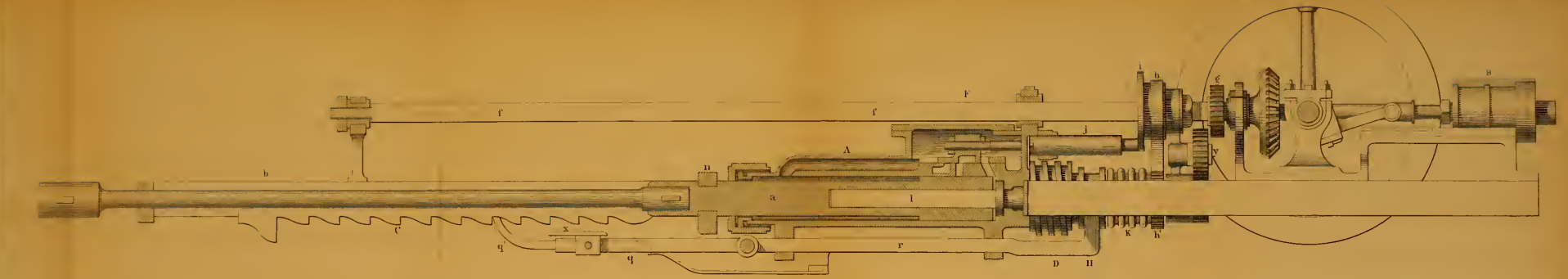
SUPPORT FOR CARRYING PERFORATORS

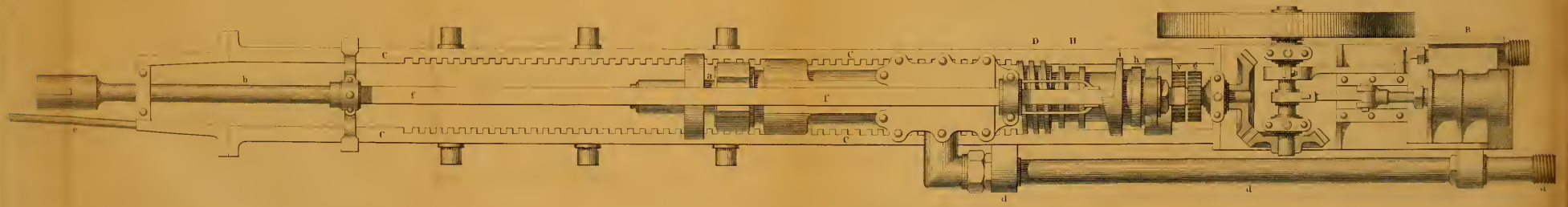
Fig 8

PERFORATOR

MONT CENIS TUNNEL.

PERFORATOR.





Scale 4in Size.

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Mr. G. NEUMANN said, on the 21st of April, 1859, he had presented to the Institution a Paper, from which he begged to make the following extract:—

"Various surveys have been made, from time to time, for the purpose of ascertaining the shortest and best direction for a tunnel through the summit of the Alps, which cross the road from Chambery to Turin; and, in 1854, I was charged, by the Victor Emmanuel Railway Company, to examine that country. The line then selected by me was near to that previously proposed by M. Maus, a Belgian Engineer; but it was slightly curved, so as to pass the tunnel under some of the lowest ground, and obtain the advantage of sinking a few shafts for the first 3 miles at each end of the tunnel.

"During the summer of 1857, a law was passed by the Parliament of Turin, authorizing the government to make a straight tunnel, 8 miles long, and to construct and employ a system of drilling machinery invented in England, and proposed to be used on this work by three Sardinian Engineers."

The first machine, which was tested in Savoy, was brought from England by Mr. Bartlett, the resident agent to Messrs. Brassey and Co., on the 60 miles of railway which they constructed north of this tunnel, under Mr. Neumann's direction. This machine was inspected by the Piedmontese Engineers, reported on to the Chamber of Deputies at Turin, and served as a model for those now in use; the former being worked by steam-power, the latter by compressed air.

Supposing that the shafts above-mentioned had been commenced on the 31st August, 1857 (when the works were begun), and that the advancement at each face had been at the rate of 180 mètres (197 yards) per year, the tunnel would have been completed for a distance of 4,700 mètres at the Bardonnêche end, by May 31st, 1862. Allowing that the machinery had been fully at work since the 31st August, 1857, and that it had advanced at the rate of 30 mètres per month (which was rather more than what was done by the machine during the first six months of 1863), the work would only have arrived at the same point as that obtained by the system of shafts and ordinary manual labour by August, 1870, thus giving an advantage of upwards of eight years in favour of the system of shafts. A similar advantage, but in a less degree, might have been obtained at the Modane end.

The slight curve in the tunnel would not have been found very inconvenient, as a clear line of sight could not, in any case, be obtained, owing to the gradient.

Progress of Tunnel.

	1st Jan. 1863.	1st July, 1863.	Average per Month.
	Mètres.	Mètres.	Mètres.
Bardonnèche . .	1,274	1,450	29
Modane	925	1,092	28
Total done July 1, 1863. . . .		2,542	
Tunnel when finished		12,220	
Remaining to be done, July 1, 1863		9,678 mètres	

which, at 60 mètres per month, would be finished in thirteen years and five months, that was, at the end of 1876. In the report made to the Chamber of Deputies in 1857, it was stated that each heading was calculated to advance, by means of the machines, at the rate of 3 mètres, or 10 feet, per day, and that the total cost of the tunnel would be £824,000. On the 1st of March last (when only about 2,320 mètres of heading were driven), the expenditure was said to have been £527,304. At the same date, it was stated in 'The Times' that the total cost of the tunnel, when finished, would be £2,000,000 sterling; but this sum would be far below the final cost, if the number of men employed, as given by the Author (2,540 per day), were to be maintained until the completion of the work.

Mr. Thomas Bartlett said, in August, 1853, he was invited, by Mr. Neumann, to assist in the selection of the line of Railway, from the French frontier to Modane, the point where the Mont Cenis Tunnel commenced, and he was at once convinced of the necessity of making the tunnel, as being the best means of uniting the Railway systems of France with those of Italy and Germany. But this tunnel was required to be 8 miles long, and, from its great depth below the surface, it would be impossible to sink shafts; it could, therefore, only be worked from the two ends, and this, by the ordinary means, would have taken thirty years to accomplish. These facts led him to consider the best method of facilitating the progress of the works by the aid of machinery; and, with this view, he designed a small and portable machine for boring holes in the rock. After several successful trials, made in the year 1854, he exhibited it, at work, in the presence of Count Cavour, Chevalier Paleocapa, Colonel Menabrea, MM. Grandis, Grattoni, Sommeiller, and others. In these experiments steam was employed as the motive power, though only because he had it at his command, and free of cost, while the erection of machinery for compressing air would have been expensive, and unnecessary; its use, however, had always been intended, and it had been provided for in his patent. In the year 1855, Commissioners appointed by the Piedmontese Government reported, after inspecting the above machine, that "they had seen a machine at

work, which satisfied them that the Mont Cenis Tunnel could be made in a comparatively short time, and at a moderate expense." At this time MM. Grattoni, Grandis, and Sommeiller, were engaged in erecting a "Compresseur à coup de belier," for the purpose of compressing air, for the use of the locomotives working the Giovi incline. On the 24th of May, 1856, M. Ranco, the "Commissaire Technique," applied, on behalf of the Government, for two of the boring-machines, in order to try their power of working with compressed air. In compliance with this request, the two machines were sent to St. Pierre d'Avena, near Genoa, and there many experiments were made, before a Commission appointed by the Chamber. The following were the results obtained :—

MACHINE working with Compressed Air to 6 Atmospheres, and placed 480 mètres distant from the Reservoir.

——	Diameter of Hole.	Depth of Hole.	Time.	Depth per Minute.	Rate of Machine.
In hard Limestone.	Inches.	Inches.	Minutes.	Inches.	
Machine	2	$21\frac{1}{2}$	7	$3\frac{1}{10}$	
Two good miners. . . .	2	$20\frac{1}{2}$	104	$\frac{1}{5}$	$15\frac{1}{2}$ times.
One good miner	2	$8\frac{1}{2}$	104	$\frac{1}{12}$	$37\frac{1}{2}$,,
In Sienite.					
Machine	$1\frac{5}{8}$	$14\frac{3}{4}$	$4\frac{1}{2}$	$3\frac{1}{4}$	
Two good miners . . .	$1\frac{5}{8}$	$15\frac{3}{4}$	50	$\frac{3}{10}$	11 times.
Grey Sandstone.					
Machine	$1\frac{5}{8}$	$23\frac{1}{4}$	$2\frac{1}{2}$	$8\frac{1}{4}$	
One miner	$1\frac{5}{8}$	23	87	$\frac{1}{4}$	33 times.
Gypsum.					
Machine	2	$23\frac{1}{4}$	1·57	$11\frac{3}{4}$	
Two good miners. . . .	2	$31\frac{3}{4}$	113	$\frac{3\cdot5}{10}$	34 times.
One good miner	2	$19\frac{1}{2}$	113	$\frac{2}{10}$	59 ,,

On the 18th of April the Commissioners concluded their investigations, and shortly after made a report to the Chamber; whereupon, Count Cavour introduced, and passed, a bill for the construction of the Tunnel.

At the time the bill was under discussion, Colonel Menabrea, who was a member of the scientific Commission, said: "Certainly, the mechanism of Mr. Bartlett worked with compressed air and acted equally well as with steam; but this machine, having been constructed with a view to work with steam, was found more complicated than if, in the first instance, it had been

made to work with air; besides, the machine had to be regulated by hand: this was a defect. In consequence of this, M. Sommeiller suggested the idea of combining a perforator of greater simplicity than that of Mr. Bartlett, and having the advantage of being self-acting, in advancing with more or less rapidity, according to the hardness of the stone acted on. The experiments which have been made with these machines have demonstrated that compressed air would not only act as a motive power, but that, applied to the perforation of rocks, rapid progress would be made, and resolve with advantage the problem of economy of time in the cutting of the tunnel. In order that you may have some idea of the rapidity of this operation (which many among you have lately seen for yourselves at Genoa), I will proceed to give some numerical statements. Generally—whether it be the mechanical perforator of Mr. Bartlett or that of M. Sommeiller—the holes are made from fifteen to twenty times faster than by hand; so that, in working for the space of fifteen minutes only upon a piece of limestone, the mechanical perforator bores a hole of 0·492 mètre in depth; while a couple of miners do only 0·022 mètre in the same time. Such are the results of the observations received on all hands. Mark well, that it is not a very complicated machine; it is, on the contrary, very simple, and when we shall have studied it more, it will be still further simplified."

In this speech, Colonel Menabrea had given him credit for having invented a machine which worked from fifteen to twenty times faster than by the ordinary method by hand labour; but said, in effect, that in consequence of its being worked by steam, it could not be used in the Mont Cenis Tunnel. It had, however, done as much work when operated by compressed air as when steam was employed. The Colonel had also stated, that a machine had been made by M. Sommeiller, which worked as fast and as satisfactorily as the one in question; but M. Sommeiller's machine, when tried on the last day of the meeting of the Commission, only struck one blow, and could not be made to move again.

Mr. Bartlett added, that his machines remained five months at Genoa, and that, although he had incurred heavy expenses for their carriage, no further notice was taken of them. He also observed, with regard to the work done by the machines in use at the Mont Cenis Tunnel, as compared with his own machines, that the former bored holes $1\frac{1}{4}$ inch in diameter, 3 feet deep, in 20 minutes, or $1\frac{8}{10}$ inch per minute; whereas the latter, as would be seen by the experiments made at Genoa, bored holes $1\frac{5}{8}$ inch in diameter, instead of $1\frac{1}{4}$ inch in diameter, into grey sand-stone, of about the same hardness as the rock at Mont Cenis, and at the rate of $8\frac{1}{4}$ inches per minute, instead of $1\frac{8}{10}$ inch per minute, or $4\frac{1}{2}$ times as fast. In very hard limestone he had bored a hole of

2 inches diameter, instead of $1\frac{1}{4}$ inch, or $2\frac{1}{2}$ times as large, at twice the speed, or if the diameter of the hole were reduced to the same size, at twice the speed with which the boring was now being carried on in the tunnel.

Mr. D. S. SUTHERLAND said, he had only recently returned from the Mont Cenis Tunnel works, where he had passed some months, and, having minutely inspected all the operations, he could bear testimony to the extreme accuracy of the Author's description. He had placed on the table specimens of the rock at Modane, on the French side. It was of a quality exceedingly difficult to work—being soft in some places and hard in others; the drills, constantly tending to seek the softer material, engaged themselves in the holes, and their extrication was a matter of difficulty and time;—thus the rate of advancement was not so great as in a rock perfectly homogeneous. To bore holes 1 mètre in depth and $1\frac{3}{4}$ inch in diameter, in this description of rock, occupied from 25 minutes to 30 minutes; while in a hard but homogeneous rock this could be done in 20 minutes. Lately, a new system had been employed, which enabled the workmen to make more progress than formerly. With the old system, it was necessary, in making one hole, to use drills, of four different dimensions—viz., $4\frac{1}{2}$ centimètres, 4 centimètres, $3\frac{1}{2}$ centimètres, and 3 centimètres in diameter, owing to the wearing of the cutting faces;—and thus, a chamber was formed slightly conical, smaller at the base than at the entrance—most unfavourable for blasting purposes. With the new system one drill made a hole 1 mètre in depth, with the base nearly the diameter of the entrance, in from 10 minutes to 15 minutes. The holes in the Modane end were now driven in a different manner from that described in the Paper—but the description was still true of the method at Bardonnêche, and was formerly so of that in use at Modane. As would be seen by referring to the diagram (Plate 3), about four large holes, each 4 inches in diameter, were made, and surrounded with smaller holes; the large ones were not charged, the smaller ones were, and by the explosion the rock was blown into the large holes—a considerable breach being formed. It was tried, with the old drills, to place the holes so that one should cut the circumference of the other, and thus form a breach without blasting; but this was found to be impossible owing to the engagement of the drills, and the difficulty of extricating them; but with the new system, not only could this be done, but, in consequence of their superior cutting power, the drills could make a hole of 6 inches diameter, in the same time that it used to require to make one of 4 inches with the old tools. By the former system, the result of the blasting to make the first breach could not be relied on; often portions of the rock at the base of the holes were left, which had to be cut

out with chisels, before the after-discharges could be made, causing a great loss of time ; but by cutting into the circumference of one hole in making another, the breach was at once obtained. The effect of the after-discharges was certain to blast the rock to the bases of the holes, and an advancement to the full depth of the chambers was assured. With the old system, though the holes might be made a mètre in depth, the actual advancement at a shift would frequently be only from two-thirds to three-fourths that distance. It was stated in the Paper, that the mechanical work of making the holes in the heading occupied from 6 hours to 8 hours, the average number of holes being 80 ; but he thought the time generally required to perform that amount of work was longer, for though in the softest rock he believed it had been done in 5 hours, he thought 8 hours was too short a time for accomplishing the work in difficult material. From the accounts of the rate of advancement, since September last, nearly up to the present time ;—where the rock was non-homogeneous, or excessively hard, it had taken 12 hours or 13 hours to make the 80 holes. In December last, a better advancement was made. The perforation was through rock, a specimen of which he had the pleasure of showing, a schist, with occasionally a quantity of pyrites imbedded in it ; and also a soft and perfectly homogeneous material that he had taken for coal, and there was still some doubt whether it was not a species of anthracite coal. In that month, the work was advanced 60 mètres, nearly,—averaging about 2 mètres per day, at one face. This was a higher rate of progress than had ever been before attained in the same period of time. In the beginning of the year a different material was struck : non-homogeneous, containing veins of quartz and hard stone ; this reduced the rate of advancement to about half a mètre a day, but this retardation did not last long. A seam of very hard but perfectly homogeneous rock was arrived at, and this was perforated more quickly ; showing the great advantage of working in homogeneous material. At the beginning of the month of February, 1864, the rate of advance was $1\frac{1}{4}$ mètre per day, and at the Modane end the length of tunnelling accomplished was 1,320 mètres.

The Author, in describing the machinery employed in the perforation, had stated as a necessary function of the machine, the injection of a stream of water into the hole, to clear out the débris as the work advanced ; but this was not really necessary, though it no doubt tended to accelerate the work. About 40 of the holes were made without the use of water ; for it was found that its use in the upper part of the heading was most distressing to the workmen engaged in the lower series of holes—the backward splash of water, mixed with the débris from the holes, making the perform-

ance of their duties a matter of extreme difficulty for any length of time.

With respect to the rotary motion of the drill, an improvement had been introduced, by the brother of M. Germano Sommeiller, which he would endeavour to describe. There was a twist in the barrel of the drill-holder—with each stroke of the piston, the drill advanced straight, but in returning, this twist, by a very simple arrangement, caused it to move slightly on its axis; and as this went on, stroke after stroke, the revolutions of the drill were completely and surely effected. By this means the complicated machinery of the ratchet and pall, constantly liable to get out of order, was dispensed with, and a great improvement had been made in the machine.

It was stated in the Paper that the operation of charging and firing the mines perforated by the machines, occupied from 1½ hour to 2 hours—but at the Modane end of the tunnel, he had found that the least time expended was 2 hours, and it had frequently been 6 hours. This great difference of time arose from the fact that with the old drills, and the old system of making the first breach, it was very difficult to place a small hole exactly equidistant from each of the two larger holes; hence, when the charge was fired it blew the rock out into the hole where it found least resistance, and left a column or piece of rock which, as he had before described, was required to be cut out by the miners before they could proceed to charge the surrounding holes; for it was a settled fact, that the amount of the ultimate advancement depended upon the depth and size of the first-made breach. By using many drills of decreasing diameters, as by the old plan, the holes being conical (the apex towards the base), the line of greatest resistance between the large and small holes was at the base, and of course the powder very seldom destroyed the rock quite to the bottom of the holes; but by using drills that made a hole perfectly cylindrical, and also by cutting out (without blasting) the first breach, the effect was rendered more certain. The system of blasting, lately tried and approved, consisted simply in placing and discharging in the holes a cartridge of peculiar construction, which secured the blasting of the rock to the bottom of the holes, and reduced the time occupied in charging them, nearly two hours at each "poste" or shift; and this cartridge could be employed with certainty in the cylindrical holes made by the new drill. With holes of the old form it was difficult to pass any cartridge in, so as nearly to fill them, as would always be advisable; but with a cylindrical chamber always maintained of the same size, there could be no difficulty, in every case, in readily passing the cartridge to the bottom of the holes. The cartridge was formed of a cylinder of

paper, containing powder, fuse, and tamping; and the tamping, which consisted of stone, broken small, or of clean, dry sand, was rendered effective by placing in front or above the powder a wooden wedge or cone: this was all enclosed in the paper cartridge. Charging a hole consisted in simply placing one of these within it. The powder, in exploding, acted on the base of the cone, which, by its action, broke the paper enclosing the sand, and forced that sand against the sides of the hole—the cone becoming a fixed point in the hole, below or behind which the powder acted. The charge of powder varied from $\frac{1}{3}$ the depth to $\frac{1}{2}$ the depth of the hole, depending, of course, on the nature of the material; but by a perfectly secure tamping, as he had described, a greater force was obtained from a given amount of powder, and smaller charges, relatively, were needed. And by having the holes as large at the base as at the entrance, a given amount of powder could be placed nearer the base of the hole, and a better effect secured. The quantity of powder put into a hole $1\frac{1}{2}$ inch diameter, and 1 mètre deep, was in length from about 12 to 18 inches. This would be from $\frac{3}{4}$ lb. to $1\frac{1}{2}$ lb. in weight; but he had observed that 1 lb. per hole might be taken as the average charge, or a total quantity of 80 lbs. discharged per shift or "poste" to dislodge about 14 cubic yards of rock. The space between the holes varied from 6 inches to 30 inches, according as the distance increased from the first breach made. By the introduction of the new form of drill the holes were reduced in number, and the necessity of perforating a number of small holes and of charging them, to make the first breach, was dispensed with, and a considerable amount of powder saved. The drill was composed of three cutting-faces, there was a small guide-drill which cut a 2-inch hole in advance of the 6-inch drill, and to this guide were attached cheeks. The tool struck the rock twenty-one times in making a complete revolution, and by the peculiar construction of the cutting-faces, the impressions made by them crossed each other so constantly and completely that the rock was quickly destroyed. The old drill in revolving crossed the impressions in the centre only; whereas the cuts made by the new drill crossed each other more than four thousand times in each complete revolution. He had seen one of these drills make a 6-inch hole 3 feet 3 inches deep in one hour, and the same had even made three such holes in succession, equal to a chamber of 6 inches diameter 10 feet deep, and after doing this amount of work the instrument was uninjured. With the old system, as many as six drills were sometimes required to make one 4-inch hole 3 feet 3 inches deep. The new drills for the $1\frac{1}{2}$-inch holes were made exactly like the guide of the large drill. It would be seen that in turning they struck constantly towards the circumference of the hole, where was the greatest resistance.

Previous to his leaving the tunnel, another plan for making the first breach was under trial. A hole was cut in the centre, the diameter of the base being much larger than the entrance, and that large hole was charged and fired. The chamber was made thus—a frame was attached to the end of the machine bearing two circles, or guides, the one nearest the rock being the same size as the stock of the drill; the other, somewhat larger; by means of a movable joint, where the drill was fastened to the holder, a strong spring constantly pressed the drill against the inner circumference of the larger guide, causing the drill in its revolutions to describe a cone, and, as it advanced, an inverted cone in the rock. Thus a hole could be made 3 inches in diameter at the entrance, and 6 inches in diameter at the base. An unusually large quantity of powder could be placed at the base of the chamber, and with careful tamping, the shape of the hole insured the tearing of the rock and the formation of a breach of considerable dimensions by a single discharge, the others following in succession as before. It had been remarked, that the machines used for perforating the chambers in the forehead were too small and too light for the work. This fact had been already recognised by the Engineers at the tunnel; and at the time of his departure, there were about fifty machines at the Modane end of increased power, ready for work, and undergoing the necessary tests before being applied. The cylinders of these machines were increased about half an inch in diameter, with an inch or so greater length of stroke, so that they would be considerably more powerful than those hitherto employed.

Mr. Thomas Brassey said, he had visited both ends of the tunnel, in company with M. Sommeiller, and he had remarked, with satisfaction, the progress that was being made. It was, as the Author had described it, a costly operation; but cost was not a question of moment in an undertaking of such great importance and magnitude as this. He had seen no appliances in any part of the world, which made the same rate of progress as that which was effected by M. Sommeiller's operation, and yet he thought M. Sommeiller had a fair right to expect even greater results, from the fact that the machinery from which he had taken his data had made more progress than was realized in the Mont Cenis Tunnel. Why that machine should have been more effective, he could not describe; nevertheless, such was unquestionably the case. The greatest credit was due to M. Sommeiller for the perseverance with which he had prosecuted this work so far, and he was quite sure that M. Sommeiller would gladly receive any suggestions tending to the advancement of the object he was engaged upon. M. Sommeiller was not prejudiced in favour of the present system: all he desired was to arrive at the best means of accomplishing

the tunnel, and he would most courteously receive any Engineer who visited the works. At the time Mr. Brassey was there, the drills in use were only $1\frac{1}{2}$ inch or 2 inches diameter, and he suggested that greater effects would be produced by using larger and stronger tools; that there would be less vibration from the stroke, and that they would have more effect. He had subsequently heard that this suggestion had been adopted, with advantageous results. He had not personally had anything to do with these works. Mr. Bartlett and himself were engaged in making the tunnel on the line from St. Michel to Susa; but those works involved no labours beyond those of ordinary execution.

Mr. R. P. Brereton remarked, that in the year 1845, when he was superintending works in Italy for the late Mr. Brunel, a machine for piercing was invented by Chevalier Maus. Experiments were made, and the success of that machine for a long tunnel, without shafts, was considered so complete, that its employment in the gigantic operations of Mont Cenis, was by many regarded as almost certain. It would be interesting to know whether, upon any subsequent application, Chevalier Maus' machine had failed, or whether a lapse of time of twelve years had prevented its being resorted to by M. Sommeiller. It consisted of a frame of cutters, resembling ordinary masons' chisels, and it cut grooves through a face of 2 mètres square. At that time it was assumed that powder could not be used at a distance of 4 miles from the face; consequently the idea was to produce a face with grooves sufficiently deep to enable the material to be removed by manual labour. As far as he recollected, this machine cut the grooves 6 inches apart, and the material was removed by ordinary wedging.

Mr. Brassey said, he was aware of the fact that Chevalier Maus did design a machine to perforate this mountain. He could not say why it was not used. He had seen the machine at Turin, but not in operation.

Mr. E. A. Cowper said, there were two points to which attention should be directed, with regard to the machine described in the Paper. The first was as to the principle of boring. He could not agree that such a very long bar, with its cutter beyond, was the best arrangement for boring. With an ordinary jumper, or chisel, of the moderate length of 2 feet or 3 feet, a blow "told well," and made the tool do its work; whereas a very long tool did less work, and was liable to be broken. For instance, if a shaft 7 feet or 8 feet long were struck on the top with an ordinary hammer, the "vis inertiæ" was so great, that a large portion of the blow would be lost upon the chisel at the end. If the blow could be arranged to act upon the tool, and not upon the long shaft to which it was attached, he believed the blow would be much more

effective; and particularly so, if the tool were previously brought tight against its work, as in ordinary boring and blasting operations. A boring-tool, to act well, must move very quickly at the time of cutting—a slowly-moving tool, although heavy, would not cut well, and was liable to break at the cutting edge. The second point was as to the size of the machine. He thought a total of 2·4 H.P., or 1·8 H.P. on the boring-cylinder, was a very small amount of mechanical power for so important a work; it was really only playing with the work. If the tool were of much larger size, and worked with 5 H.P. or 6 H.P., he imagined the holes might be drilled more quickly than at present. With regard to the use of compressed air, he understood this machine worked with a pressure of only $3\frac{1}{2}$ atmospheres; that seemed a small pressure, and even if 5 atmospheres were used, there would be only a small amount of power to do the duty on the face of the rock. He thought the cylinder should be larger and the same quantity of air used, but worked expansively. By this means, nearly double the amount of power would be obtained, with the same expenditure, and the same apparatus for compressing the air. If the cylinder were made four times its present area, and the boring-tools larger in proportion, he believed the work would progress much faster. He was decidedly of opinion that a good machine could be made. He thought Mr. Bartlett's arrangement of introducing an air-spring between a boring-tool and a reciprocating piston-rod of an engine worked with a crank motion, by steam or air, was a very ingenious contrivance; and he understood it was not until after Mr. Bartlett had obtained most successful results with this machine, that the French machine was commenced. He could not but think that the amount of wear and tear of the French machine was excessive, as evidenced by the large number of men always at work on the repairs.

Mr. Robert Mallet said, that his views were generally favourable to the substitution of machinery for hand labour. At the present time machine coal-cutting was carried on to a considerable extent in the north of England and in South Wales. In Westphalia, Belgium, and Styria, shafts of 14 feet or larger diameter had been sunk by boring-machinery within the last five or six years; and seeing that machinery was employed as far as possible to supersede manual labour in every other species of work, he was persuaded that it would be found equally applicable in the perforation of tunnels. Its superiority in making the holes was most clearly demonstrated by the tables of the comparative results of the two systems; that there were imperfections in the machinery in use was certain, but probably practice would remove these. One difficulty in the case of M. Sommeiller's machine was, that there was only half a mètre space on either

side of the carriage at the fore-end of the tunnel, and there was therefore great delay in removing the 'déblais.' This difficulty did not exist in either Mr. Bartlett's machine, or in a machine of much merit invented by M. de Fontenay. It had been correctly observed, with respect to hand 'jumping,' that a large proportion of the workman's labour was absorbed by the inertia of the bar, and that only a small proportion of the total work done by the man was delivered from the 'jumper bar' into the rock. This was most remarkably indicated by the tables of the results, from which it appeared, that the work done upon the rock, in proportion to the total work expended, was smaller as the rock penetrated was softer; and this result was in strict accordance with theory, for the harder the rock the greater was the proportion of work delivered from the bar, into the rock at the cutting point, at a given weight and velocity of hammer and weight of bar. Thus the worst results obtained from hand labour were by working into the soft material, gypsum. He concurred in the opinion as to the value of a larger air cylinder, and the advantage of using the air expansively in the Mont Cenis boring-machine. At the same time, he did not think there was any disadvantage in the length of bar, interposed between the piston that drove it forward, and the "point d'appui" upon the rock, provided the bar itself were rigid; because the work delivered into the heavy bar was transmitted into the rock.

With respect to the use of deep holes and great charges of powder in tunneling, as had been suggested, he would observe that in some species of rock that method would be highly inexpedient; for, assuming the powder to be fired in homogeneous rock, the angle of the cone blown out would be determined by "the plane of easiest fracture," and it would depend upon the density of the material, and upon its adhesion along this plane. Therefore, with a given depth of hole, and a determinate charge of powder, the breadth of the base of the cone dislodged would be also determined; but when the base of this cone became equal to the narrowest dimensions arcoss the forehead of the tunnel, no advantage could be obtained by any further increase in the depth of the hole or in the charge of powder; but, on the contrary, loss would ensue, for the only effect would be to shatter the rock into cracks and fissures, without dislodging any stone, and to make subsequent blasting operations difficult and dangerous. He, however, perfectly agreed that, in whatever way the work was performed, the true principle was to put the first great shot in to the full depth of this cone, and to follow that up by minor holes, so directed that the planes of fracture should be produced, as nearly as possible, in a direction parallel with the sides of the tunnel. Thus the most regular perforation would be made with the least waste of powder. Various abortive projects had been formed

for piercing tunnels by boring-machines, some prior to that of Mr. Bartlett, and very recently a proposition as to the Mont Cenis tunnel had been made by M. de Fontenay, which appeared to have attracted the attention of competent capitalists, who had offered to deposit one million of francs as a guarantee of the completion of his undertaking in six years and a half. He proposed to pierce both the sides of the mountain by diagonal shafts subdividing the tunnel into short lengths, and carrying on the works simultaneously in no less than eighteen places at once, or at thirty-six headings.

Mr. C. H. Smith remarked, with regard to rock blasting, that there were cases within his own knowledge, in which the charge of powder at the bottom of the hole had not been exploded so as to produce the effect required, but had been shot out of the hole as from the barrel of a gun. This might be obviated by making the space larger at the bottom of the hole. If, for instance, the hole were $1\frac{1}{2}$ inch in diameter at the entrance, and 3 inches at the bottom, it would contain a larger charge of powder. The expeririment was tried some years ago with great success.

Mr. William Eckersley observed, that the cost of labour in this tunnel seemed to be very great. It had been stated that in this undertaking the object was progress; but, at the same time, he thought a higher rate of progress might be obtained at a less cost. Referring to the figures in the Paper, he found that 2,540 men were stated to be employed on the two faces of the tunnel: taking the wages for those 2,540 men at 4*s*. per day each, it would be found that this tunnel was costing for labour alone £190 per lineal yard, and if to that £40 or £50 were added for the cost of powder, masonry, and air-machines, there would be a total of about £240 for each yard of advance, which, contrasted with work done in England and other countries where labour was dear, was an enormous price. Rock tunnels had been recently executed in Derbyshire, on the Midland Railway extension line, between Rowsley and Buxton, at a cost of from £18 per lineal yard to £20 per lineal yard for labour. These tunnels were for a double line. Those portions of the Harecastle Tunnel on the North Staffordshire Railway that were in rock were executed at about £16 per lineal yard. The Bhore Ghaut incline tunnels on the Great Indian Peninsula Railway, driven through hard rock, cost £25 per lineal yard, including powder. These were all instances in which the cost was from $\frac{1}{6}$th to $\frac{1}{8}$th of that of the Mont Cenis Tunnel. Looking at the cost of the advanced gallery, he calculated there would be about $13\frac{1}{3}$ cubic yards of material in a yard forward. The wages of 88 machinists and 18 chargers, at 4*s*. per day each, would amount to £21 4*s*., and calculating the cost of machinery at £8 per day, there would be a total of £29 4*s*. for

removing $13\frac{1}{3}$ cubic yards, or equal to 44*s.* per cubic yard. Similar work in England would be done at from 6*s.* to 8*s.* per cubic yard even in hard rock. The number of men of all classes that could be advantageously employed in rock tunnels in England would not average more than 100 or 120 at one face. If that number were doubled for night and day shifts and for two faces, the total number employed would not exceed 450 or 500 men. He wished to draw attention to the great discrepancy between the number of men employed in ordinary rock tunnels with the number employed at Mont Cenis, and he thought a large saving might be made in that respect. It was to be expected that where machinery was employed, manual labour would be much diminished; but, looking at the large number of men employed on the Mont Cenis tunnel, it was clear that no saving in manual labour had been effected, but quite the reverse: for the number of men, employed there, was five or six times greater than would have been the case in England. The rate of progress by machinery was stated in the Paper to be three times that of hand labour; but, from his own experience of tunneling work, he believed where hand labour was employed, the rate of progress was about one-half as compared with machinery. Mr. Bartlett's machine appeared to be of a simpler character than M. Sommeiller's, and the experiments made with it gave results superior to those now obtained at the tunnel.

Mr. C. H. Gregory, V.P., said, he was much impressed with the results effected by Mr. Bartlett's machine, which appeared, not only to have bored holes of uniform dimensions, for their whole depth (a desideratum not obtained by M. Sommeiller's machine), but to have penetrated into the face of a hard rock at a much greater speed than had been yet attained by the machines now in use at the Mont Cenis Tunnel. In seeking to ascertain the causes of this difference in result, a consideration of the arrangement of the frame in M. Sommeiller's machine led him to infer that some weakness and irregularity of action might naturally be expected from it; and probably the superiority of Mr. Bartlett's machine was, in some measure, due to the steadier action of the drills, obtained by their being supported by the frame so close up to the face of the rock.

Mr. F. W. Sheilds remarked, that in quarrying rock the position of the beds was an important guide to the miners and quarrymen in determining the direction of the bore-holes; but he had not learnt from the Paper whether, in the case of this tunnel, the beds were horizontal, vertical, or sloping. He imagined that, as the machine perforations were made invariably in a horizonal direction, they would rarely happen to be placed in the most advantageous way. Now whether the "lie" of the beds were favourable or the reverse, must materially affect the quantity

of work done, and the expense at which it was executed. He had mentioned this subject, in order that the Author might give some additional information upon so important an element for the correct appreciation of the progress effected. He wished to express his strong impression of the superiority of Mr. Bartlett's machine, in simplicity and efficiency, to the one now actually employed in the tunnel.

Mr. F. J. Bramwell said, the subject of driving machinery by compressing air was by no means new to him; but he was more intimately acquainted with the working by exhaustion, as introduced and carried out by the late Mr. John Hague. These subjects were cognate, and he had had frequently to consider the most economical way of transmitting power by exhaustion. He would in the first place say a few words upon the compressing machines, more especially those of Sommeiller. He thought, as regarded the amount of work done for the power expended, justice had hardly been rendered to the machine by the Author of the Paper. He did not gather that he discriminated between the work done and the ultimate result obtained in the end of the tunnel. As regarded the work done by the compressing machine, it amounted to 72 per cent. of work for the water expended. Another 8 per cent. went in the water rising up the pipe from O to C (Plate 4). The half height of that water was 7 feet above the point of discharge, and that was simply waste: so that to the 72 per cent. represented by the actual amount of air compressed, 8 per cent., the amount due to the water rising 7 feet high, must be added, and the remaining 20 per cent. was to be accounted for in the friction of the water passing the great inlet valve, and the friction of the air escaping through the valve into the reservoir. But 72 per cent. might be considered a fair amount of duty, and if the machine were desirable in other ways, there would be no cause of complaint on the ground of want of duty. From the 72 per cent. had to be deducted the power of an 8-horse air engine employed to work the valves, so that there was not left 72 per cent. to do duty in the tunnel. With this deduction it was clear the benefit from the machine was so small, as not to have induced any Engineer of prudence to have done that which had been done at the Modane end, viz., at a place with a fall of water of only 20 feet, to employ machinery to pump up water to a height of 80 feet, to enable it to work the air-compressing machinery. This desire of identity in the air-compressing machines at the two ends of the tunnel, seemed to him to have led the Engineer to a complexity of machinery in the case of the low lift, which was not justified by any extraordinary merit in the compressing machine itself.

The next matter he had to refer to was the air-compressing pump used at the Modane end alone, in substitution for the above-

mentioned machine. The Author of the Paper was apparently under the impression, that the use of water in a pump of that description, in order to obtain a perfect delivery of air at every stroke, was a novelty. Now at the time the Portable Gas Company was in existence, the pumps used to compress the gas were plunger pumps into which mercury was put, and the plunger being driven down the mercury at the first stroke overflowed at the valve, and by that means, all cavities being occupied by the mercury, the full amount of gas was discharged at every one of the succeeding strokes. But without going back so many years, or referring to mercury as the filling liquid, he need only take them to the period of the meeting of the Institution of Mechanical Engineers held at Glasgow in 1856, where there was a Paper read by Mr. Randolph[1] on an air pump used to compress air to work an engine in mines, and in this pump, water was introduced to get rid of the clearance, and also to absorb the heat produced by the compression. The plan, it appeared, answered perfectly, for after the machine had been six years at work, not the slightest repair was required. It was stated that the pressure at which it was worked was 30 lbs. above the atmosphere, and the distance from the surface of the pit to the engine was 974 yards, yet the difference of pressure between the pump's end and the engine was only 1 lb. He therefore thought that there was to be seen in Glasgow in 1856 an engine which in principle contained all that was to be found in the machinery now under notice.

There was a prevalent opinion that clearance in a pump used for the purpose of compressing air was fatal, by causing an absolute waste of power in relation to the work done, and that therefore it was most desirable that every particle of air should be expelled. Without going into an elaborate calculation to prove that this was not so, he would content himself with a simple illustration. Suppose a pump worked with so much clearance, that the delivery valves were, at the end of the stroke, on the point of opening to allow the air to escape, but did not open; evidently in the return stroke the expansion of the compressed but unescaped air would afford as much aid to the piston as it had required power to work it to compress the air, and in that way the piston might go backwards and forwards, doing no work but consuming no power except that required to overcome the friction. In fact, it might be shown that whatever clearance was left in the pump, although it did away with a portion of the effect produced, equally did away with a portion of the power required; and therefore clearance was not so fatal as some supposed.

It had been suggested, that it was undesirable to have a heavy

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[1] *Vide* "Institution of Mechanical Engineers, Proceedings, 1856," p. 145.

tool, or implement, between the air cylinder and the face of the rock; but this must be taken with some reservation; no doubt it was undesirable to have the tool too heavy, but it was most important to have it heavy enough. It was quite true that if a heavy boring bar, or tamping bar, were hammered upon, a great portion of the blow would be uselessly expended: on the other hand, if the bar were lifted and allowed to fall to act as a hammer, then a heavy bar was an advantage. Applying these two propositions to a horizontal bar propelled by a pressure of air, acting through a considerable distance, then the bar itself must be the hammer; for if there could be got a bar of no weight, and there were a given load on the piston, then whatever might be the length of stroke, the final work would be no more than the pressure on the piston: but if there were used a bar of proper weight, then the effect of the pressure on the piston throughout the stroke would be accumulated in the heavy bar in motion, and thus the full effect would be delivered to the rock.

The Author stated that about 250 strokes were made per minute. He would take 240 as a more easy number, being a multiple of the number of seconds in a minute. Now 240 double strokes per minute = a double stroke in the fourth part of a second, or a half stroke in the eighth part of a second; but allowing for the fact, that there must be some pause at each end of each stroke, it was not too much to say, that the half stroke must be done in the tenth part of a second. The average stroke was stated to be 7 inches, but the distance a body would move in the tenth part of a second, if impelled by a force equal to its own weight, would be only 1·92 inch, or about $\frac{3}{11}$ of the 7 inches. In order therefore to make a body move through 7 inches in the tenth part of a second, it would require a force of $3\frac{2}{3}$ times gravity acting to effect it. Now it had been stated, that the total effective pressure on the piston was about 217 lbs. If this were divided by $3\frac{2}{3}$, it would give 59 lbs. as the weight of the parts to be moved through 7 inches in the tenth part of a second by the force of 217 lbs. This would be equal to a bar of about 2 inches in diameter by 5 feet 9 inches long. If a heavier bar were used, the pressure would be inadequate to accomplish the full stroke of 7 inches; but if a much lighter bar were used, although the stroke would be made in less time, there would not be sufficient weight in motion to absorb the work given out in the cylinder, and to redeliver it on the rock.

It had also been stated in the Paper, that it was proposed to increase the pressure of air, which the Author thought was judicious. Mr. Bramwell did not know how it was intended to be done with the contrivance of hydraulic machinery, unless there were the means of increasing the head of water, as the apparatus used could only give an uniform pressure, not a variable pressure.

But assuming that, either by making use of a greater head of water to drive the first-described compressing apparatus, or by using the compressing pumps, the pressure were increased, the result would be this: So long as air engines were working expansively no doubt there might be got out theoretically all the power that had been consumed to compress the air to drive them, but it seemed these air engines were not worked expansively, but simply at full pressure. Now the power to compress air, in relation to the amount of air compressed, and to the pressure at which it was compressed, might be taken as the converse of the power developed by the expansion of air, or steam, from the terminal pressure in the pumps down to the atmosphere; and the relation between this pressure and the work given out by a non-expansive air engine would be the relation between the effect produced by steam used at the terminal pressure, and not expanded, and such steam expanded down to atmosphere. The air engines were now working at 5 or 6 times the pressure of the atmosphere above atmosphere, and if the power given out by them at that pressure were taken at 1, the power required to compress the air was 2·14; whereas if they worked at 7 atmospheres that power would be increased to 2·28. If on the contrary they worked as low as 3 atmospheres absolute, or 2 atmospheres above the pressure of the air, then the power would be diminished to 1·64 times the work given out. Therefore, to his mind the improvement in economy was to be made rather in reducing than in increasing the pressure of air. He believed if the pressure were reduced, and the size of the cylinders increased, and if due regard were paid to the weight of the rods, in relation to the pressure on the piston, better effects would be obtained. The present power given out by this engine was exactly one-third of that which there was in the water; 28 per cent. was lost in the compressing machine, and the remainder was lost as long as expansion was not used in the air engine, and the actual loss was even more than stated, because the statement assumed that the whole power was doing work to perforate the rock, but it would be found that a large amount of air in addition was required to work the little machine which worked the side valves of the air engine.

Allusion had been made to the machine of Mr. Bartlett, and the question had been asked, how it was it did so much better work than the machines employed in this tunnel? One reason for that was very evident. It appeared to have been made of a reasonable size, instead of being made too small, and it commended itself by the total absence of numerous complicated parts, which appeared to abound in the machines under consideration.

He believed the great use of these discussions was to bring forward everything bearing on the subject under consideration. In

that view he begged to contribute a description of a machine invented by M. Leschot, for boring by rotary motion by means of the use of a diamond cutter. With this machine it was stated two men could bore a hole of 18 inches deep in hard rock in an hour, and it was also said that the diamond cutter having bored through 160 mètres of granite showed no signs of wear. The cost for a set of diamonds he believed was 135 francs, and the whole apparatus cost only 2,300 francs.

The following was a translation of the description of the diamond-cutter machine, furnished by the inventor:—

"The apparatus invented by different Engineers consists generally in implements of percussion set in motion by mechanism. In those most used, the boring tool is directly attached to the piston-rod of a steam-engine, or of a compressed air-engine: on the machine being set in motion, the boring tool is thrown with force against the part which is to be bored; and thus by successive percussions the required effect is produced. These means, although they consume a considerable amount of power, are generally effectual when used in rocks of medium hardness; but their success is indifferent indeed, when employed in really hard rocks, such as quartz and felspar, which, being harder than steel, soon cause the tools to lose their form or to break. Moreover, few Companies can support the expense necessary for the establishment of the apparatus for the compression of air, and so are deprived of the effect which might otherwise be obtained from the application, at the end of a tunnel, of considerable mechanical force. Here, therefore, is a deficiency which I have sought to supply.

"In designing the perforator, I proposed, as objects to be attained, rapid perforation coupled with the employment of the least possible force; and thus beneficially to utilize manual labour. The possibility of reproducing mechanically the well-directed work of the intelligent miner, that is, of having the power to form the perforations so as to profit by the configuration of the rock and the course of the veins, thus obtaining the greatest amount of excavation possible, with the smallest number of perforations, and consequently, the minimum expenditure of labour and powder.

"The essential part of the machine is composed of a tube, which, by means of very simple mechanism, turns and advances at the same time—the amount varying according to the nature of the rock. The end of the tube intended to operate in the rock is provided with a metal ring, in which is set small fragments of black diamonds—a kind of diamond harder than the ordinary diamond. This kind having no brilliancy, nor transparency, is only used in the state of powder for cutting gems. They are of small price, and even after having been used in the machine, inasmuch as I employ only their natural angle, have lost nothing appreciable of their weight, and preserve all their commercial value. This ring, fastened by a bayonet-joint at the end of the tube, is applied to the rock and penetrates it, and thus forms an annular opening round a cylindrical core. In this manner, the instrument works only on the circumference of the hole which is to be made, and therefore I economize labour. As the hole advances, the core passes into the tube, and when the hole is perforated to the desired depth, there is no further operation required to remove from the rock the core which the cutter has left, as this core adheres only by its base, and can be detached with the greatest ease, the slightest blow being sufficient to break it off. The portions cut away are carried off by a slight current of water passing through the tube.

"This apparatus is equally serviceable for railway works, or for mines, for the quarrying of very hard rocks, and also for the sinking of shafts, by modifying the form of the support of the tube. It is, likewise, a means of making deep holes of a greater diameter than can be tamped in the ordinary way. The use of diamonds for making the cutter's edges allows of operating upon the hardest and most compact rocks with the greatest facility.

"It would be easy to place several boring tools on a single frame to form a compound machine moved either by power or not; but up to the present time it has not been done, it being more advisable to make a simple machine so light that two men can fix it and work it. The machine occupying the space of only one man, and capable of making perforations well placed in any position, being persuaded that one hole, suitably disposed, produces more effect than ten which are not.

"The machine is composed of a framing of two sides in wrought iron, between which slide and turns the perforating apparatus, properly so called, which, moreover, can be completely contained within the sides, like the blade of a knife in its handle. On the sides are two racks of malleable cast iron, which allow of the perforator being placed at a suitable height; there is also a set screw, which serves to fix the whole, vertically or horizontally, against the rock. The perforator has a left-handed screw at its back end, by which, as it rotates from left to right by means of a pinion placed upon, and sliding along, an axis parallel to it, the perforator would recede as it turns, were it not that the part on which the thread revolves is in a gun-metal nut 0·12 mètre long, and having also a movement of rotation. It is, therefore, evident that the real forward movement of the tube is equal to the difference of the two movements which are communicated to it—namely, of the forward movement caused by the rotation of the nut, and of the backward movement caused by the rotation of the tube in the nut. This arrangement of a differential movement is adopted, to admit of very slight advancement for each turn, and to be variable at will, according to the nature of the rock. Moreover, when the hole is perforated, nothing is required to draw back the tube, except to ungear the two wheels of the differential movement, so that it is not necessary to change the direction of the rotation of the tube, which would involve a risk of tearing the ring, or crown, which carried the diamonds, and of losing it in the hole.

"It is clear that the injection of water, which is given by means of a small garden pump, could readily be worked off this machine; but this is not done, in order to prevent complications. The two small set screws, placed in front, serve to fix the machine perfectly against the rock, and to prevent the harmful vibrations which would otherwise take place in consequence of the work. It may be remarked that the machine is completely symmetrical in relation to a plane passing through its vertical axis; so that the fly-wheel, the small crank-handle (which serves for the up and down movement along the racks), and the palls can be put to the left or the right; for all the axes are hollow, and these before-mentioned movable parts are provided with the driving-squares, and can be inserted into the hollows at either end of the shafts; and thus the machine may be made to work close to either the right or the left side.

"In shutting up the machine it rotates round a shaft, which serves, at the same time, as a support to the small pinions which gear with the racks.

"As regards the rotation in a horizontal plane, it is effected in the following manner—having conducted the machine to the front it is erected vertically, the upper set screw is slightly pressed on the framing to steady it, the apparatus is then set as regards the horizontal plane. Then as regards

the vertical plane, the nut placed on the shaft is tightened up, which fixes the boring tool in a position more or less inclined in a vertical plane; the upper set screw is then tightened up, as also are the two front screws. The machine being thus fixed, and the differential movement being disengaged, the crank of the fly-wheel is turned in such a way that the tube revolves from right to left, but its thread being left-handed, and the nut remaining fixed, the tube advances with great speed towards the rock, seeing that at each turn it goes forward the length of the pitch, which is 4 millimètres. Having arrived at 1 millemètre from the rock the motion is stopped, the differential movement is geared together, a small click placed in front is set in action, so that the workman cannot make a mistake in the direction of the rotation, which is forced to be from left to right. The advance is at the rate of $\frac{1}{10}$, $\frac{2}{10}$, $\frac{3}{10}$, &c., of a millimètre for each turn, until the hole is completed; then the differential movement being ungeared, and the workman still turning in the same direction, the tube comes out of the rock. All these operations are long to describe, but in reality take but half a minute, as to execute them it is sufficient to push a small ungearing bolt. One man can work one of the machines for three-quarters of an hour continuously, but it is better to have two men working alternately, as in this manner more useful work is obtained.

"Nothing can be more easy than to work this machine by compressed air, or by steam, if the occasion presented itself, by placing on the bar a small piston with an oscillating cylinder, and to replace the fly-wheel by a toothed wheel. The total weight of the machine is 150 kilos., and the water expended is 50 litres for 50 centimètres; but this quantity will serve indefinitely, as the heavy dust it contains deposits rapidly.

"With a relay of two men has been obtained—

In the granite protogyne of the Alps . .	0·60	of a mètre an hour.
In Jaspe-rouge de Savoie	0·40	,, ,,
In the Quartzite Talqene, very compact and hard, Tunnel de Suavage	0·25	,, ,,
The diameters of the holes being always .	0·035	mètre.

With a strap, transmitting a half-horse power approximately, the granite protogyne was worked through at the rate of 1·40 mètre and more: all, in fact, depends on the speed of the rotation. The daily advance is according to the nature of the stone, being less as the rock is harder."

Mr. Evan Hopkins remarked, that in tunneling operations the expense and the rate of progress varied considerably, depending upon the nature of the rock. The average price for labour in hard, primary siliceous rock was from £4 to £12 per cubic fathom, or at the rate of 10*s.* to 30*s.* per cubic yard, according to the hardness of the rock, the position of the bands, the joints of the structure, and the size of the tunnel: the smaller the size of the tunnel, the greater was the cost per cubic yard. In driving through the compact, slaty, micaceous rock in North Wales, the cost, including all charges, for tunnels of about 36 feet in area, was from 8*s.* per cubic yard to 12*s.* per cubic yard. In the secondary slate rock, homogeneous and soft in its character, like that of Mont Cenis, holes could easily be made by drilling; but in hard, siliceous primary rocks, holes could only be made by the ordinary

mode of boring. The latter process could certainly be much more expeditiously carried on by machinery than by hand labour, and much time would be thereby saved; but he considered that advantage, in the system now adopted, was neutralized by the extra cost attending the preparations for blasting, and the necessity for the repeated removal and refixing of the machine.

Mr. JOHN HAWKSHAW, Past-President, remarked, that the Italian Engineers were not present to speak for themselves; and that, under the circumstances, an opinion could only be formed from the facts which had been given. As far as he saw of this machinery, he was at a loss to conceive why Mr. Bartlett's machine, if steam were objected to, should not have been worked by compressed air as well as the others. He was sure the Institution would be willing to give Mr. Bartlett that measure of praise which he deserved in this matter. At the same time, the object of the Paper was to elicit opinions as to the general progress and mode of constructing this tunnel; and it was quite clear to him, that a tunnel of this description ought not to cost £240 per yard, as calculated by Mr. Eckersley. It was about 24 feet in height by 25 feet in width. If, indeed, it were necessary to cut it to a true lineal form, the cost would certainly be considerable; and if it were also necessary first to drive a 10 feet heading in that hard material, the expense of construction would be still further increased. There was, however, a mode of dealing with it apart from the machinery, and that would be to abandon the formation of this smaller tunnel, and to blast out from the middle of the face a much larger quantity of rock at a time, using a larger quantity of powder, and not being particular to preserve those exact dimensions of 24 feet by 25 feet. Practice would determine what the charge of powder should be. By that means, he should expect the work to be done at less cost. He thought that the system of punching all these very small holes in the face of the rock might be a costly mode of construction. At the same time it required a more intimate knowledge of the work than he possessed to venture on any positive opinion on that point.

Mr. G. P. BIDDER, Past-President, said, that he most entirely relied upon Mr. Bartlett's statements, and although the Engineers of the tunnel were not present, he thought that circumstance should not debar the expressions of opinion upon assured facts. He agreed that the mechanical appliances for boring through the rock did not appear to have been eminently successful, for if the cost were anything like £240 per yard forward, as calculated by Mr. Eckersley, and if the progress was $6\frac{1}{2}$ yards per week, the extra cost could not have been compensated by the expedition, as in the London clay, 4 yards could be completed

per week. But whether this enormous cost was incurred by the use of inefficient machinery, or by maladministration, was a difficult question to decide—possibly it was owing to a combination of both causes. A case had lately come under his notice, in which a Government establishment was manufacturing precisely the same description of article and the same quantity per week, as were being manufactured in a private establishment; while the wages at the private establishment were £50 per week, and at the Government establishment £350 per week. So that he was justified in saying, that it was difficult to decide whether the excessive expenditure had been incurred through defective machinery or through maladministration.

Mr. Bartlett's experiments showed, that his machine could accomplish three times the rate of speed that was attained in the Mont Cenis Tunnel, and it was inconceivable that a machine which had been worked by steam could not be worked by compressed air: it was a mere question of the substitution of so many pressures of air per inch, for so many pressures of steam per inch, and also of adaptability to particular circumstances. Therefore, if three times the actual rate of speed could be accomplished by the use of Mr. Bartlett's machine, the extra cost would be justifiable, because the whole subject for consideration was not one of mere dry cost per yard, but of the period within which it would be possible to open the tunnel for public traffic. An expenditure of more than £200 per yard for a progress of 6 yards per week was an unwise expenditure, whereas if that amount were laid out in accomplishing double the progress, it would be a wise and judicious expenditure.

Mr. T. Sopwith, Junior, said, that to meet fully some of the objections that had been made to the system pursued at the Mont Cenis Tunnel would require time for consideration, and his reply must therefore necessarily be incomplete, the more so as the discussion touched upon points, that were difficult to reply to without preparation. But he thought that other objections had arisen through misapprehension of statements made in the Paper, and those objections he trusted he should be able to remove. As regarded the economy of the system, he was not able to advocate it, at least so far as it was carried out at the Mont Cenis works alone; and so strongly had he felt this, that, in order to estimate the comparative cost of driving galleries and tunnels upon M. Sommeiller's system, and by hand labour, he had taken a hypothetical case, assuming as a basis results that might fairly be expected from improved machinery, and he had emphatically directed attention to the fact, that the comparison was not special to the Mont Cenis works, but of general application. The grounds of the comparison were fairly stated,

and the terms might be altered, if it were thought that they were over estimated or under estimated, and that a different proposition or result would be arrived at. But while admitting the comparison to have been rough, he could not, after due consideration, perceive that any essential alteration was needed in the result of the proportionate cost of the two systems, as he had stated it. Mr. Bartlett might certainly congratulate himself upon having been the first to move in the practical application of machine-boring; and he would have further cause for satisfaction when a more general application led to its further development and to an increased economy in its use. It was to be regretted that no information about Mr. Bartlett's machine had been made public. With regard to the assumed superiority claimed for it over those now in use at the tunnel, he would be the last to disparage its value, but he thought it due to M. Sommeiller to point out some most important differences, not so much in the construction, as in the actual principle of the two machines.

In M. Sommeiller's machine the air was admitted as the motive power, and the air forced the boring tool to and from the forehead. In Mr. Bartlett's machine, if compressed air were used, it would not work directly upon the boring tool. The air which would force the boring tool in the latter machine was nothing more or less than a cushion or spring actuated by the strokes of a rotary engine, acting in a second cylinder. The power thus produced was, therefore, altogether independent of the compressed air, or whatever might be used as a motive power, and was an indirect application of it; whereas, in M. Sommeiller's machine, the application of the motive power was direct. This, it must be admitted, was a difference in principle which could not be passed over. He might say of Mr. Bartlett's results, that they seemed to be extremely satisfactory, but it must be remembered that they were experimental. The experiments certainly had been made frequently and fully, but M. Sommeiller's results, extending over a trial of two years, with all the difficulties of a new system, must be considered more practical and reliable than those which had been made by Mr. Bartlett's machine. With respect to the assumed superiority of Mr. Bartlett's machine in anything like the proportion of 3 to 1, it would be most unfair to take the result of any experiments with the former machine, to compare with the actual results of the latter. He had little doubt that M. Sommeiller's machine in experiments, had made equal progress to that made by Mr. Bartlett; and it was within his own experience, that a machine which by experiment gave as good results as either of the above-named, nevertheless proved a complete failure in practice. It was not necessary that he should remind the members, that tunneling was no Rule of Three question, to be solved in such a manner as saying—Such a

machine could bore 20 inches in 7 minutes, how much should it bore in a month? Some remarks had been made upon the length of the boring-tools in M. Sommeiller's machine; this length might be objectionable in one sense, but in another it was an advantage. If they were shorter, the machine would, no doubt, be more steady and compact, but it would not have the same aptitude for being readily set to work in the forehead. The bottom of the rock was generally uneven, resulting from the explosions, so much so, that it would be impossible, without dressing the bottom, to bring the frame close up to the forehead. The machines were therefore made long, to obviate that necessity—as also the frequent alteration of rails; with the present length of machines and borers, the frame need not be brought nearer to the forehead than about 8 feet. During the discussion, in calculating the cost of these works, the wages of the 2,500 men employed had been estimated by Mr. Eckersley at five francs per day each. In the first place, 2,500 men were not employed at the tunnel. That number constituted the whole staff upon the works, employed at the time when many alterations and additions were being made, and eventually the number would be greatly reduced. No doubt many were incidental to the working of the machines, and of these a full statement was to be found in the Paper; but the question was not so much the number of men as the rate of wages that had been assumed, namely, five francs per day. On this subject the information in the Paper, having been obtained from the Mining Engineer in charge at the tunnel, was exact. The miners were paid 2 frs. 10 cts. per day—other classes of workmen were paid 2 frs. (1*s.* 7*d.*) per day, and boys, 1½ fr. (1*s.* 4*d.*) per day; so that, on the average, the rate of wages paid for labour, even allowing for the ten foremen machinists employed in the tunnel and at the pumps, did not at the most exceed 2 frs. 50 cts. per diem, equal to about 2*s.* A rate of wages was, however, assumed of 4*s.* per day for 2,500 men, which would give rise to some misapprehension and serious error, having the effect, in fact, of almost doubling the cost of the work. So also, with respect to the cost of the advanced gallery, he found 4*s.* per day was the assumed rate of wages, when in reality it was only 2*s.* per day. To estimate roughly then the cost of the tunnel, take 2,500 men at 2*s.* per day, divide that by 3 yards per day advancement at the two ends (less than was done in June last), and the cost for labour was under £85 per yard; and as the labour of all the workmen was included in the 2,500, £40 per yard was a liberal estimate for the cost of materials, &c., for walling and finishing the tunnel. This would give £125 per yard, in place of £160, or of £240 per yard, as stated in the course of the discussion. In estimating the proportionate rates made by the systems of hand labour and machine labour, there were in-

disputable facts which would, he thought, answer the objections which had been made to the conclusions he had drawn. The rates formerly attained by the Piedmontese miners (and perhaps there were no better in Europe) were known. It was found that during three years or four years of hand labour, the average progress was not more than about 18 inches per day, whilst the results in similar works, as obtained from machine labour, at the time of the Author's visit, and maintained during the month of June last year, and since that time, as stated by Mr. Sutherland, were 4·719 feet, affording at once a comparison in favour of the machine of at least 3 to 1. The 2 mètres per day was obtained in rock rather softer, and did not make so fair a comparison.

It had been suggested, that it was desirable to adapt these machines for working at different angles. They could, in reality, be applied at any angle; but as had been explained in the Paper, practically this was of little use in the labour operations, as it was necessary, or at least advisable, to bore a number of holes, and shatter the rock into small fragments, for the convenience of removing the 'déblais.' Although the same quantity of material could have been dislodged with a much smaller number of holes judiciously placed, it was a fact that the holes were bored so quickly, that a slight increase in their number was not objectionable; while, on the other hand, if the masses of rock brought down by the explosion were large they could not be quickly removed, and they would require to be broken up, while the machines would be standing idle 150 yards from where the explosion had taken place. It was, therefore, found better to put in a greater number of holes, and to place them so close together, that the pieces brought down by the explosion should not, on an average, exceed a cubic foot in size.

It had been stated that 72 per cent. of the power was given out by the "Compresseur à coup de belier," and that he had not done justice to it. What he meant to convey was this: that, assuming the air to be used unexpansively, it was not in the nature of things that the air-machine should give out more than 50 per cent. of the power employed to compress it; that, however, was not meant to apply to the "Compresseur à coup de belier," nor did it suppose any defect in that machine; it would be seen by reference to the expansive course of steam, or other elastic fluids, that it was impossible that more should be given. He considered the pump to be an admirable machine for the purpose to which it was applied; and the loss was clearly owing to the air not being used expansively in the perforators.

Although total clearance might not be necessary, he certainly could not see any benefit to be derived from intentionally permitting it, and allowing air to re-expand when power had already

been exerted to compress it, and would again be employed at the succeeding stroke for the same purpose; and in the case of the "Compresseur à coup de belier," any air left in at the end of the stroke would be an absolute loss of power. If the pressure of compressed air were diminished and the cylinder of the perforator made larger, as has been recommended, the machines would then be too heavy, for they already weighed 6 cwt. The rates of progress recently obtained had been questioned. In 1861 very little progress was made—the advance, in that year, having been only 170 mètres; it was the first year of the inauguration of an entirely new system, a time when the greatest difficulties were to be met, and he might say, were overcome. It was, therefore, not a favourable time for making observations. One cause of stoppage that year was with the "Compresseur à coup de belier," which suffered some serious accidents. There also appeared to be an impression, that with two years' experience in working, better results as to progress might have been made. That impression appeared to have arisen from the statement, that the rate of advance, between July, 1861, and some day in 1863, had been only 650 mètres in a period of 720 days; but it was to be borne in mind, that that period embraced the year 1861, to which he had just referred, when a progress of only 170 mètres was made; therefore, not the rates during those years, but rather the rates at which the forehead was now being driven, should be taken as the result of two years' experience.

In reply to an inquiry as to the actual cost per yard or mètre, Mr. Sopwith said, that was a question which the Engineers did not evince any disposition to enter into, one that could not be pressed upon them, and, moreover, he did not pledge himself to defend the economy of the Mont Cenis Tunnel establishment or administration. A work new in principle was, perhaps, never before launched into on so large a scale; it was natural, therefore, to expect that many errors would be made. His own estimate of £125 per mètre just given was a very rough one; and he was not aware that any estimate of the cost of the tunnel had been published other than what was stated before the Italian Parliament by the Minister of Public Works, which was £120 per mètre, as the total cost for the finished tunnel.

Mr. John B. Fell said, that widely different opinions had been expressed on two questions, namely, as to the probable period of construction of the tunnel, and as to the actual and estimated cost of the works. With regard to the former, the Author had given the lengths executed up to Midsummer, 1863, and had stated that the Engineers of the tunnel hoped to be able to increase the rate of progress twofold or threefold; and if so, that the tunnel might be finished within five or seven years from the present time.

On the other hand, the French Government had allowed twenty-five years from the 1st of January, 1862, for its completion, and a premium of £20,000, and £24,000 per annum for as many years as the tunnel could be opened within that period. The Italian Minister of Public Works, General Menabréa, had taken a medium between these two extremes, and had estimated the time requisite for bringing it to a conclusion at twelve and a half years from January 1st, 1863. These several estimates fixed for the completion of the tunnel, the years 1868 to 1870, or 1875, or 1887. The early period referred to by the Author appeared to be based on mere conjecture and not on facts, or on the results obtained up to the present time.

The eminent Engineers, who were successfully devoting their best energies to the completion of this great work, no doubt did well to aim at accomplishing their task within the shortest possible period; but this zeal conveyed no proof that the accelerated progress they so much desired had yet been made practicable. And it was perhaps calculated rather to diminish than to increase the confidence of the public in the work, when statements were made which differed so widely from the actual results hitherto attained.

From notes taken at repeated visits to Bardonnêche and Modane during the last two years, he found the usual rate of progress in the heading was stated at $1\frac{1}{2}$ mètre per day—the holes being bored by the machines to a depth of 1 mètre, and each of the two blasts in the twenty-four hours bringing away three-quarters of a mètre of rock; but this rate of working had never been long sustained; for at times the hard quartz veins became more frequent, the machinery required to be repaired or added to, and from various causes there arose unavoidable delays.

The actual quantity of work done at Bardonnêche was—

			Rate per Year.
1857—1860	Manual labour .	724 mètres.	241 mètres.
1861	Machinery . .	170 „	170 „
1862	ditto . .	380 „	380 „
June 30, 1863	ditto . .	176 „	358 „
		1,450 „	
At Modane—			
1858—1862	Manual labour .	925 „	231 „
June 30, 1863	Machinery . .	167 „	334 „
	Total to June, 1863 . .	2,542 „	

The last, or fifth half-year of working by machinery at Bardonnêche, gave a rate of progress of 704 mètres per annum, at which rate the remaining 9,678 mètres could be completed in thirteen and a half years from that date. No doubt, the machinery and

mode of working might be improved; but, on the other hand, there was the possibility of arriving at granite rock and unforeseen causes of delay. The Minister had therefore exercised a wise discretion, in not leading the Italian people to expect, that the progress of the tunnel could be accelerated to such a degree as to gain more than a year and a half over the maximum rate of progress hitherto attained, and in naming the year 1875 as the probable period for the opening of the tunnel.

On the very interesting question of the cost, there appeared also to be a considerable difference of opinion, the Author estimating it at £125, and Mr. Eckersley at £240 per lineal yard. Upwards of twelve millions of francs had been expended, of which the fixed machinery and buildings appeared to have cost four millions; consequently, more than eight millions of francs had been expended on 2,542 mètres of tunnel executed, being at the rate, including the proportion of the four millions, of £140 per lineal mètre. The Minister's estimate of fifty millions of francs for the tunnel (namely, sixty-five millions, less fifteen millions for the line to Susa,) gave a cost of £163 per lineal mètre.

Considering, however, the immense national and European importance of the Mont Cenis route, as well as the amount of capital invested in railways on either side of the Alps, the cost became a secondary matter, since the communication was indispensable, and the want of it was becoming every year more keenly felt. To provide for this want, during the twelve years before the tunnel could be opened, a project had been laid before the Italian Government for constructing a locomotive railway, or tramway, over the pass, a sketch of which project, as it embraced some points of novelty, might not be uninteresting to the Members, and it was also closely connected with the tunnel question. It had been proposed to lay rails on the existing Government road (Route Royale) between St. Michel and Susa, leaving free a sufficient width to accommodate the local traffic; where needful, the road would be protected from avalanches and snow-drifts by a covered way. The steepest gradient of the pass was 1 in 12, and on such gradients, down to 1 in 20 or 1 in 55, a third rail would be laid in the centre of the way, raised about 9 inches above the other rails.

The engines for this particular service would be provided with two pairs of horizontal wheels, which, with the vertical wheels, could be driven by one pair of cylinders, or by additional cylinders. These wheels being made to press upon the centre rail by an arrangement by which the pressure could be varied according to the road, provided the adhesion necessary for ascending and safely descending inclines of 1 in 12. An experimental engine of this description had been constructed and its powers tested

during the last four months on the steep inclines of the Cromford and High Peak Railway, the use of which had been liberally granted for the purpose by the Directors of the London and North Western Railway Company. On a future occasion, he would present to the Institution an account of this system of working steep inclines by locomotive engines, describing the results which had been attained. On this question, he would at present only state, that it had been proved to the satisfaction of many practical men who had attended the trials, that small tank engines of that class, weighing not more than 16 tons, with a supply of coke and water, would take trains containing from 80 to 100 passengers from St. Michel to Susa, and from Susa to St. Michel in about four hours, and goods trains, weighing 32 tons, in between five and six hours, in place of from nine hours to twenty hours for the former, and several days for the latter, as at present. The whole distance was 48 miles, and the rise from Susa, in 17 miles was 1,593 mètres, or 5,225 feet. With such an arrangement, passengers leaving Paris at eight p.m., would arrive in Turin at four the following afternoon, instead of at two on the morning of the third day, and would reach Genoa at half-past nine p.m., or twenty-five hours after their departure from Paris, ten hours at least earlier than by steamer *viâ* Marseilles.

On the opening of the tunnel, the rails would be taken up, and a largely-developed traffic transferred to the tunnel route. It might, at first sight, be supposed that the expense of locomotive power for carrying passengers and goods over the Pass would be so much greater than the cost of the same through the tunnel, that the former route might not be practicable, or, in other words, would not commercially pay. Such, however, was not the case; on the contrary, with a traffic of tenfold the existing amount, charging interest on capital in both cases, and the respective cost of locomotive power, and other working expenses, the total cost per passenger and per ton of goods would be thirty per cent. less by way of the Pass than by the tunnel, the time of transit being nearly two hours longer. Consequently, what would be a temporary provision for ten years on the Mont Cenis, could, with still greater advantage, be made a permanent one on any other mountain Passes.

A comparison of the heights and lengths of the two routes would show that the difference against the Pass was not so great as might be imagined; thus the elevation of the Mont Cenis Pass was 6,907 feet, while that of the tunnel was 4,388 feet; again, the distance between Susa and St. Michel by the former route was 48 miles, and by the latter 42 miles. The difference against the summit route was therefore 2,519 feet in height, and 6 miles in length. The average gradient in the former case was

1 in 26, and in the latter 1 in 46—the maximum being 1 in 12, and 1 in 28 respectively.

Assuming the traffic on the Mont Cenis route to be increased tenfold, the traffic would consist of 300,000 passengers, and 200,000 tons of goods per annum; and the cost of working, including interest on capital expended, would be as follows:—For the tunnel route £261,250, and for the summit, or Pass, £186,250, leaving a difference or saving in favour of the latter of £75,000 per annum. Consequently, for other less important Passes, the latter system being the more economical, might be the most desirable.

Mr. W. C. HARRISON said, he understood it had been stated, that after making the holes for blasting, it was found that in consequence of the cartridge not going to the bottom of the hole, the quantity of rock thrown off was not what it ought to have been. This must have been a serious loss, for it was difficult to place the machine a second time, in such a way as to take advantage of the part of hole not broken off. It occurred to him that a simple method would remedy this defect, and would give all that was due to the depth of the hole. He proposed to enclose the cartridge in a tin tube and pass them both down to the bottom of the hole; the tube might, possibly, be saved by drawing it back each time, but if not, the increased quantity of rock thrown off would compensate for its loss. It had not been stated how far the cartridge went into the hole, but supposing it not to have reached the bottom by 5 inches or 6 inches, the air in that space must have materially diminished the effect of the explosion.

With respect to the tools used in boring, he would observe, that their ordinary defect was a liability to become clogged with the borings. He had invented a machine which bored holes $1\frac{1}{8}$ inch in diameter, and 1 inch deep, in one minute, or at the rate of 5 feet per hour, and this was in hard slate rock. It was provided with a bar, and at a quarry in North Wales, it had bored holes of the above diameter 2 feet deep. It could work at any angle to 180 degrees; the rate of boring by the usual method was, for holes $1\frac{1}{8}$ inch in diameter and 1 inch deep, 5 minutes, or 20 inches per hour. Encouraged by this success, he had made another machine, expressly for boring tunnels, larger and stronger than the first, capable, as had been proved, of boring holes 2 inches in diameter and 4 feet deep, at the rate of 10 feet per hour and 16 feet per hour; the motive power employed to work it was steam. The timber bed of this machine was 7 feet long and 2 feet 8 inches wide, the height was 5 feet 6 inches, and the two wrought-iron tubular pillars were each 3 inches in diameter.

Mr. J. F. BATEMAN said, there were some points, within his own experience, which enabled him to draw a comparison between

machine work and manual labour. In the construction of the works for supplying Glasgow with water from Loch Katrine, the aqueduct passed for about 10 miles through mica slate, a hard, tough, tenacious rock mixed with quartz, which rendered the working very difficult. In many cases, in an 8-feet tunnel, a progress of not more than $2\frac{1}{2}$ yards or 3 yards per month was made, working day and night. The actual cost of removing the material, by blasting, varied from £1 per cubic yard to £2 per cubic yard. The time occupied in boring a hole 20 inches in depth, which was the ordinary depth, was about an hour and three quarters, and every inch in depth generally required the employment of a fresh chisel. The diameter of the hole was about $1\frac{1}{4}$ inch. On each 8-feet face every gang at night took in with them 60 drills or chisels (which frequently bored little more than 60 inches), and brought out 60 dulled chisels in the morning. The rock in some places was exceedingly hard. He did not know how far it was analogous to the material operated upon in the case of the Mont Cenis Tunnel; but he gathered that the latter material was of a schistose nature, largely mixed with quartz, and in that respect, much resembled that of the Loch Katrine tunnels. These were a few facts by which a careful comparison could be drawn between the cost of hand labour and of machine work. In the Glasgow water-works, there were often upwards of 100 faces going at the same time, and therefore it was impossible to employ machinery. Many plans of machines had been submitted to him, but he had determined that, in tunneling with so many faces, machines were not applicable under the circumstances. There were 13 miles of tunneling in a length of about 23 miles of conduit.

He could readily believe that the application of machinery was desirable in a large tunnel, where it was worked from one end, and where a plentiful supply of air could be obtained, and would present greater advantages than manual labour.

Mr. J. Scott Russell said, he had been furnished with some items of information by an Austrian Engineer, which he thought would be useful. He said that the application he had seen made of gun-cotton to the blasting of rock, enabled him to state that very favourable results might be obtained from it in driving tunnels. In Hungary the use of gun-cotton instead of gunpowder had been attended with the following advantages: 500 lbs. of gun-cotton were equal in effect to 3,200 lbs. of gunpowder, and owing to a particular action the blast holes could be placed much wider apart; the saving of labour from this circumstance was a diminished expense in the ratio of 16 to 28, as compared with gunpowder. In a given bulk, the gun-cotton had a greater force, in the ratio of 2 to 1; and in a given weight a greater force, in the

ratio of 6 to 1. No smoke resulted from the discharge, and only a small amount of heat, and the work could be done much more rapidly.

Mr. BRUNLEES presented a drawing of a machine which he had seen at work boring slate, in a quarry in North Wales, in 1855. The inventor was Mr. E. J. J. Dixon, of Bangor, who described the machine, as follows:—

"I now beg to send you a tracing of my rock-drilling machine, showing hollow shaft and force pump, etc. I invented this machine in 1854, when you were Engineer of the Railway from Gorsedda Quarry to Portmadoc. In 1855, I had the pleasure of showing you the machine at work in the said quarry. I there used to bore a hole 4½ inches in diameter, at the average rate of 3 feet per hour, by manual labour at the lever of a large ratchet brace. The holes were usually made from 14 feet to 25 feet into the face of the rock, and according to the length of the hole the charge was apportioned. The dislodgment of rock was from 600 tons to 3,000 tons at each blast."

Mr. T. SOPWITH, junior, observed, through the Secretary, in reply to Mr. Fell, that so far from estimating the time required for the completion of the tunnel by mere conjecture, he had given the basis on which he had formed his calculation. In one instance he had taken a rate of progress already realized, and that in the infancy of the application of boring machinery, when it was stated that 9 years 2½ months would be occupied in completing the work; whilst in another case, when expressing an opinion that an advancement of 2 mètres per day at each end would be attained, he had remarked that under those circumstances the tunnel would be finished in 6 years 7 months. Mr. Fell said, that with an annual progress of 704 mètres at Bardonnêche, 13½ years would be required to complete the remaining 9,678 mètres. As, however, the Modane end might be supposed to advance at the same rate, it would perhaps be more correct to say 6¾ years rather than 13½ years.

February 23, 1864.

JOHN ROBINSON M'CLEAN, President,
in the Chair.

The discussion upon the Paper, No. 1,106, on "The Mont Cenis Tunnel Works," was continued throughout the evening, to the exclusion of any other subject.

March 1, 1864.

JOHN FOWLER, Vice-President,
in the Chair.

The following Candidates were balloted for and duly elected :— Charles Andrews, Frederic Murton, Thomas Summers, and Henry Winteringham, as Members; John Allison, Captain James Palladio Basevi, R.E., Samuel Brown, William Dyce Cay, Charles Cubitt, Sidney Field, Andrew Cassels Howden, Douglas Arthur Onslow, Charles Trew Prebble, Allen Ransome, jun., Henry William Schneider, Thomas Sopwith, jun., Samuel Utley, and Arthur Valentine, as Associates.

The discussion upon the Paper, No. 1,106, on "The Mont Cenis Tunnel Works," was continued throughout the evening, to the exclusion of any other subject.

March 8 and 15, 1864.

JOHN FOWLER, Vice-President,
in the Chair.

No. 1,105.—"On the Resistance to Bodies passing through Water."[1] By GEORGE HENRY PHIPPS, M. Inst. C.E.

IT was the Author's original intention to have confined his remarks to that part of the resistance to solid bodies passing through water, which has reference to the surface, or frictional, resistance only. But he found that this plan would not permit the use of a method he has sometimes found convenient for determining that quantity, namely, that of deducting from the total resistance of the body the approximate quantity of all the other resistances, except friction. He has, therefore, entered into the whole question of resistance, which has necessarily led him to extend this Paper to a greater length than was at first proposed.

The resistance encountered by solid bodies, when passing through a fluid, is well known to consist of two principal parts. The first, occasioned by the effort necessary to overcome the inertia of the fluid in advance of the moving body, as well as that which fills in the vacancy continually forming behind, will be called the Inertial Resistance. The second, occasioned by the friction of the surface of the body against the fluid with which it is in contact, will be called the Frictional Resistance.

If the laws applicable to the determination of the resistances were of the character usually assigned by theory, the computation of the resistance to a body of given form, moving at any specified velocity, would be a very simple matter; but, unfortunately, experiment and theory differ as widely on this subject as do the opinions of scientific men, especially upon Frictional Resistance.

For the determination of the Inertial Resistance, the existing theory is based upon the force required to impel a plane surface of given dimensions through the water at any velocity, in a direction at right angles to itself. This resistance consists of, and is usually divided into, two parts; the first, appropriately called the Plus, or Positive Resistance, occasioned by the pressure of the

[1] The discussion upon this Paper extended over portions of four evenings, but an abstract of the whole is given consecutively.

fluid against the forward side of the plane; and the second, the Minus Resistance, or that diminution of pressure which always takes place at the rear of any body set in motion in a fluid.

Reasoning from the universally admitted fact, that the force of impact of a column of water directed against a plane surface at rest, and the force of reaction against the side of a vessel from which the same stream has issued, are equal to the weight of a column of water of the same base as the column making the impact, and of twice the altitude due to its velocity, it might appear logical (as it did to Newton and others) to infer, that a precisely similar resistance would be encountered, if the experiment were reversed, and the plane made to move instead of the water. On closer examination, however, it will be seen, that the similarity of the two cases is incomplete; for, whilst in the impact first alluded to, every molecule of the fluid strikes the plane, with its full velocity, and loses the whole of its vis viva; in the case of the plane moving through a mass of surrounding water, the pressure upon its forward side is propagated to some distance in advance, whereby the fluid to be removed comes to be acted upon gradually, and never acquires a velocity equal to that of the plane itself. Thus the pressure against the plane is diminished, but theory has not yet succeeded in assigning the ratio of such diminution.

The experiments of Dubuat, and of Beaufoy, show the above resistance to be nearly equal to once only the height of the virtual column, where planes equal to one square foot in area were employed (Plate 5, Figs. 1 and 2). There is reason, however, to conclude, that when the magnitude of the plane is increased, the resistance increases in a higher ratio than the area. Because, if, as supposed by the Author, the water retreating before the plane makes its escape laterally, as well as 'end on,' the larger plane having less perimeter in proportion to its area, allows of a smaller proportionate escape in the former direction, and the total velocity to be imparted to the fluid thus becomes greater. The experiments of Beaufoy confirm this view; for they show, that at the velocity of $13\frac{1}{2}$ feet per second, the total resistance of a plane equal to 1 square foot was 196 lbs., whilst with a plane equal to 3 square feet, the total resistance per foot became 214 lbs.

The Positive Resistance, therefore, or that on the forward side of the plane, will, probably, for all large surfaces, be at least as much as once the height of the virtual column. Calling R, the positive resistance, $64 \cdot 2$ lbs. the weight of a cubic foot of sea-water, v, the velocity in feet per second, and g, $32\frac{1}{6}$ feet, then

$$R = \frac{64 \cdot 2 \times v^2}{2\,g}.$$

With regard to the Minus Resistance, by a well-known principle in hydraulics, whenever a fluid at rest is put into motion, behind a plane surface retreating before it, its pressure upon the plane is diminished. A pressure, therefore, equal to the above diminution, must first be applied behind the plane, to restore the hydrostatic equilibrium; after which the positive pressure, previously described, is to be added; the two together representing the total resistance.

The theoretical diminution of pressure behind any plane put into motion in a fluid at rest, is, by the application of the hydraulic law just referred to, equal to the weight of a column of water whose base is the moving plane, and altitude that due to the velocity. Here again, however, and probably arising from a similar cause, as in the case of the Positive Resistance, the experimental resistance falls considerably below the theoretical.

It appears natural to suppose, as it in reality happens, that the Minus Resistance should be less easily determinable than the Positive Resistance; for whilst the latter only differs from theory, on account of the transmission of pressure in advance of the moving plane, in the former the affecting causes are numerous.

There is no doubt, that every variation in the proportions of length, breadth, and depth of the moving body, makes a difference in the facility with which the fluid veins, put into motion by the forward part of the body, can enter the vacancy momentarily forming astern. If, for instance, the body be very short, all the lateral motion of the fluid at the forward end, is opposed to its easy entrance behind; whereas, when the length is considerable, the disturbance at the forward end has time to subside, before the after end of the body comes up to the same spot; and this is no doubt the reason of the advantage so frequently attending the operation of lengthening a ship. This operation of cutting a ship in two, and inserting a new portion at the midship section, appears to the Author most instructive, as to the Minus Resistance; for it often happens that a vessel constructed on lines giving a very fair 'run' aft, may have a considerable length inserted, and be loaded down to the same draught, without any increase of resistance. Now, of course, in such a case, there must be an increase of Frictional Resistance commensurate with the superficial area of the surface added; and the only way in which such increase of resistance can be neutralized is by diminished Minus Resistance. The conclusion, therefore, is inevitable, that the total Minus Resistance prior to the alteration, must have exceeded that, after the alteration, by the whole amount of Frictional Resistance added.

In confirmation of these views, the experiments of Beaufoy may

be referred to, as showing, that whatever were the forms of the bodies he experimented upon, a diminished resistance was always the consequence of adding to their length, by the insertion of a piece in the midships.

Now, as the very existence of the Minus Resistance is entirely attributable to the inertia of the quiescent fluid about to close in upon the 'run' of the vessel, it is clear that if, by any means, the fluid has imparted to it an initial velocity in an outward direction, the effort required to bring it back into contact with the vessel will be greater. But such an initial outward velocity must always be given to the fluid when acted upon by the inclined bows of the vessel. When the vessel has a long parallel shape at the midships, this outward velocity gradually diminishes, and is lost by the time the fluid has to fall in at the after part; and hence the saving of power by increasing the length amidships, causing often a greater improvement than an equal addition of length to the vessel's run. It is evident, however, that this improvement can never be carried further than to destroy all the divergence of the fluid, leaving still in existence all the Minus Resistance due to the angle of the 'run,' as if the vessel were moving in undisturbed water.

If, then, it be imagined, for the sake of illustration, that the divergence of any particle of water at the stern is 1, when the inward motion due to the angle of the stern moving in undisturbed water is 2, the total minus resistance would be as $(2 + 1)^2 = 9$, against $2^2 = 4$, after the insertion of an additional length capable of destroying the whole of the divergence.

In the well-known case of the ship 'Candia,'[1] a vessel whose length was originally 281 feet, breadth 40 feet, draught 18 feet, and area of midship section 523 feet, when a new portion, 33 feet 6 inches in length, was added at the midships, she made, when loaded down to the same draught, as nearly as possible, the same speed of $12\frac{1}{2}$ knots, with the same power. Now the frictional surface added by this alteration, amounted to about 2,440 feet, which at the coefficient for a new iron ship equal to $\frac{1}{211}$th of that surface, acting at right angles to itself, is equal to $11\frac{1}{2}$ square feet. Again, if the Minus Resistance 'proper' of the vessel be considered as that due to an assumed average slant length of the 'run' to the base, as 7 to 1, and for the present, the Minus Resistance be computed as that due to once the virtual column, this would be equal to the resistance of a plane of $10\frac{1}{2}$ square feet area, moving, as before, at right angles to itself. Thus it will be seen that prior to the alteration, when the total resistance of the vessel was the same as afterwards, the Minus Resistance

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xvi., p. 342.

must have equalled $11\frac{1}{2} + 10\frac{1}{2}$ square feet, and after the alteration only $10\frac{1}{2}$ square feet, because the balance was absorbed in friction.

Although, therefore, the Author is aware of the experiments made by Dubuat,[1] with square prisms about 1 foot square, and differing in length from a simple plate up to once, and three times, the length of the side, giving results for Minus Resistance considerably lower than the above, he is inclined to place more reliance upon the large practical results exhibited by the alteration to the 'Candia' and other similar cases.

Under all the circumstances, and considering the magnitude of the surfaces employed, the Author is of opinion, that if the Minus Resistance be taken as equal to the column due to the velocity, that quantity will certainly not be greater than the resistance experienced in actual practice.

Calculating from the above data, and calling R′ the Minus Resistance of a plane surface equal to 1 square foot area, moving through sea water at right angles to itself, the resistance will be

$$R' = \frac{64{\cdot}2 \times v^2}{2\,g}.$$

Therefore, the total resistance, including both the Plus and the Minus Resistances, will be

$$R + R' = 2\left(\frac{64{\cdot}2 \times v^2}{2\,g}\right).$$

When the displacing planes are inclined to the direction of motion (Plate 5, Figs. 3 and 4), the simplest manner of estimating the theoretical resistance, bearing in mind that the resistance to be overcome is still due to the inertia of the fluid, is to compare the area of the displacing plane with the area of its projection upon another plane at right angles to the direction of motion, when the resistance of the inclined plane will be to that of its projection, inversely as the squares of the areas. Calling R, the resistance of the inclined plane, a, the area of the projected plane, r, the ratio of the areas of the projected and the inclined planes, and S, the area of a detached plane moving square to itself, having an equal resistance with the inclined plane,

$$\text{Then } S = \frac{a}{r^2}, \text{ and } R = \frac{S\,64{\cdot}2\,v^2}{2\,g}$$

expresses the Positive Resistance in the direction of the motion.

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[1] *Vide* D'Aubuisson, "Traité d'Hydraulique." 8vo. 2nd Edition. Paris, 1840, pp. 295 and 306.

Similarly, the Minus Resistance of an inclined plane is expressed by

$$S = \frac{a}{r^2}, \text{ and } R' = \frac{S\,64{\cdot}2\,v^2}{2\,g}.$$

It will be observed, that the Positive Resistance thus obtained is denominated the Theoretical Resistance, because, although based upon the previously stated quantities, which profess to express the real resistance of a plane moving at right angles to itself, other corrections are still required.

In reality, the Positive Resistance of an inclined plane is always greater than the above (Plate 5, Figs. 5, 6, and Plate 6, Fig. 8), and the experiments of Beaufoy show, that the difference continually increases, in some proportion to the sharpness of the inclination. Having adapted to cubical bodies measuring 1 foot on the side, angular prows, the slant lengths of which, in proportion to the width of the base, were as the numbers 2, 3, 4, and 6, the ratio of resulting resistances, to those arrived at by calculating the pressure at once the virtual column, were as 1·1 to 1, 1·98 to 1, 3·24 to 1, and 6·95 to 1. Although the above experiments exhibit so large an increase of resistance, beyond that afforded by the previous calculations, the Author is inclined to think, that when the moving planes are large, the increased pressure only extends for a limited distance along them,—a distance, however, for the present indeterminate. A few words may, perhaps, be usefully bestowed upon the apparent reason for this increased pressure, and for the Author's opinion that it extends over a portion only of the plane. He conceives that the increase is owing to the circumstance of the forward end of the plane having to overcome the inertia of the fluid with which it is brought into contact almost instantaneously, whilst for the portion of the plane further back, the fluid against which it has to operate is already in motion when the action takes place.

Whilst upon the subject of the great increase of pressure upon inclined planes, a striking example may be referred to in the ordinary screw propeller, each unit of the surface of which may be regarded as a plane surface, moving through the water at a determinate angle to itself. In the case of the 'Rattler,'[1] in one of the best results, where the pressure on the end of the screw shaft was 3 tons, 18 cwt., as measured by the dynamometer, taking the known slip at the time, and doubling this for a supposed current following in aft, and using the rules previously given for the determination of the Positive and Minus Resistances, a pressure of 213 lbs. only is the result, equal to the $\frac{1}{41}$th part only of the actua. pressure.

[1] *Vide* Bourne "On the Screw Propeller," p. 115. Lond., 1852.

Reference may also be made to the screw propeller, as confirmatory of the opinion previously offered, concerning the limited distance along an inclined plane to which the increased pressure extends; it being found in practice, that no perceptible increase of pressure is obtained, by giving to the blades a greater area of surface, than will fill up about one-third of the whole area regarded as a disc.

Before quitting the subject of the enormous pressure sometimes exerted upon inclined surfaces, reference may be made to the ricochet of a cannon-ball, from the surface of water upon which it makes an oblique impact.

The term Additional Head Resistance will be given to the above increase beyond the theoretical quantity; and in the absence of a theoretical solution to determine its amount, the following empirical method is offered (Plate 5, Figs. 5, 6, and Plate 6, Fig. 8). It agrees tolerably well with the results of Beaufoy's experiments, and is proposed to be used on inclinations of the displacing planes, forming the vessel's prow, up to 15, slant length, for 1, of base. The method consists in adding a constant quantity equal to a plane surface $\frac{1}{7}$th of a foot in area, for every foot in depth of the draught of water. Calling the depth d, and S as before, the area of a plane having an equal resistance, then $S = \frac{d}{7}$.

It will be observed, that the calculations hitherto given for obtaining the Positive Resistance, have been confined to those cases where the head ends of the bodies considered are bounded by plane surfaces (Plate 5, Fig. 7). When these boundaries consist of curved surfaces, as in the case of ships, the method adopted is to divide the depth of the draught of water into a certain number of horizontal portions; and then to divide each portion again into a number of separate parts, each of which may be regarded as a plane surface, and be calculated accordingly. Then the sum of these parts, of course gives the whole resistance.

Having examined those portions of the Resistance to Bodies passing through Water which are attributable to its inertia, the Frictional Resistance, which at high speed is regarded as the most important, will now be noticed. The friction of water in motion, against any surface with which it is in contact, has at all times attracted the attention of hydraulic engineers, as affecting, to a very great extent, the quantity of fluid capable of being passed through pipes, or water courses, in any given time. The surface friction of floating bodies has also received much consideration, particularly of late, owing to the magnitude and the velocity of the vessels propelled by steam power. Whilst, however, theory and experiment have been found to agree sufficiently well for the purposes of the hydraulic engineer, it cannot be said that the

ship-builder has felt the same confidence in the few experiments upon the friction of external surfaces which are open to his examination.

Direct experiments upon the friction of the surfaces of floating bodies appear to be so simple, and as the proper relation between the length and breadth of ships can never be established while this question remains in abeyance, it seems not a little singular, that in a maritime nation like this, no new and conclusive experiments should have been made, having regard to the effect of roughness, in increasing resistance, since those of Beaufoy in 1798.

The chief distinction between the friction of solids, and of fluids, consists in the fact of the latter being entirely uninfluenced by pressure, and that it increases nearly as the squares of the velocities; a property perhaps bringing it more properly within the meaning of the term Inertial Resistance, than of the friction proper of solids. The only direct experiments, with which the Author is acquainted, upon the friction of external surfaces, are those by Beaufoy.[1] They were tried by drawing through the water, at various speeds, two smooth painted planks, of similar sharp forms at the ends, and differing only in the extent of surface presented by each to the water. There were two sets of experiments, one made in 1796 and the other in 1798. In the latter, which are considered the more reliable, the difference in the area of the friction planks was exactly 46 square feet, which at a speed of 10 feet per second, was found to give a resistance of 0·339 lb. on the square foot, and to increase nearly as the squares of the velocities, namely as the 1·949 power.

These experiments having been made with very smooth surfaces, the influence of roughness in increasing friction must now be referred to. This effect is well-known to all practically engaged about ships and boats. In sailing and rowing matches, the greatest care is taken to thoroughly cleanse the bottoms of the competing vessels, which are also frequently covered with a varnish, or other substance repellent to water; and in large and rapid steam vessels, the effect of the fouling of the bottom in diminishing speed is well known. It was stated by Mr. Watson, in his Paper "On the Communication between London and Dublin," read during the last session,[2] that although great care was habitually taken to cleanse the bottoms of the vessels periodically, yet that, with the moderate increase of fouling which unavoidably took place, the average time of 3 hours 52 minutes for the trip, was increased to 4 hours 12 minutes. The time being thus increased in the proportion of 1 to 1·086, if the engine power utilized remains constant, the

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[1] *Vide* Beaufoy's "Nautical and Hydraulic Experiments," vol. i., p. 487, London, 1834.

[2] *Vide* Minutes of Proceedings Inst. C. E., vol. xxii. p. 574.

resistance of the vessel will be increased in the proportion of the cubes of those numbers, or, say, nearly as 1 to 1·28. That is, if the vessel thus retarded, were urged up to its original speed, its resistance, compared to the clean condition, would be as 1·28 to 1. This extra resistance being, however, clearly due to the frictional part only of the total resistance of the vessel, in the case under consideration nine-tenths of the whole, the surface resistance or friction will have been increased nearly one-third.

It has occurred to the Author, that the frictional resistance of the surfaces of steam vessels, may be approximated to, by considering all the circumstances of the vessel itself when propelled at a given speed. Thus, if the indicated horse power be the accurate representation of all the power employed, if all the other resistances and losses, besides the frictional resistance, can be approximated to, and if the superficial area in contact with the water be also known, it is clear that the resistance due to each square foot of surface may be easily deduced. In the calculations of the steam ship 'Leinster,' to be hereafter alluded to, this method gives for the surface resistance, when perfectly clean upon the trial trip, at a speed of 30 feet per second, 4·26 lbs. per foot,[1] or an addition of about two-fifths to the coefficient of Beaufoy; and this is sufficient, together with the other calculated resistances and losses, to account for the whole power given out by the engines. It may also be added, in support of this method of arriving at the surface resistance, that as the sum of all the other resistances and losses, is to the frictional resistance, only about as 1 to 9, it would result that—even in the extreme case of, on the one hand, doubling the former resistances, or on the other of neglecting them altogether, —the frictional resistance would only be altered the $\frac{1}{9}$th part, added or deducted as the case may be, thus making a difference of only about $\frac{1}{2}$ lb. per square foot, at a velocity of 30 feet per second.

Another method of arriving at the coefficient of friction, based upon the resistance of water flowing through pipes, has been given by a Member of the Institution, in a formula for obtaining the resistance of ships.[2] In this formula, the minimum resistance of the surface of an iron ship, is taken as always equal to that which water meets with in flowing through a pipe in which the water flows at the same rate as the ship advances, and this the Author of the formula fixes at 25 oz.[3] per square foot, at a speed of 15 feet per second, the rate of

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[1] Since the Paper was written, the accuracy of the above coefficients has been confirmed, very nearly, by the examination of another vessel, the 'Atrato,' of different type from the 'Leinster,' the details of which are given in the Appendix, page 340.

[2] *Vide* Minutes of Proceedings Inst. C. E., vol. xvi., pp. 355, *et seq.*

[3] This is with fresh water. If it be with sea water, this value must be increased as the specific gravity, or as 62·5 to 64·2.

increase being taken as the square of the velocities. When the vessel's surface becomes very foul, an extra resistance is directed to be provided for. That this coefficient is greatly in excess, will be shown by applying it to the case of the Holyhead steamer 'Leinster,' the surface, and other elements of resistance, of which the Author has carefully calculated. In this vessel the total indicated power of the engines amounts to 4,751 H.P.; deducting $\frac{1}{5}$th for observed slip, and $\frac{1}{10}$th of the remainder for friction, indirect action, air pump, and all other losses, there remains 3,421 H.P. as the total available power of the engines. Now the surface of the ship in contact with the water is 13,000 square feet, which, with a velocity of 30 feet per second, would, according to the preceding data, give a friction equal to $6\frac{1}{4}$ lbs.[1] per square foot, and represents an amount of power equal to 4,395 H.P. or 974 H.P. in excess of the whole available power of the engines, without any allowance for the other resistances of the vessel.

Having touched upon the friction of water passing through pipes, as a proposed means for ascertaining the friction of exterior surfaces, it should be observed, that until very recently, the theory held by eminent hydraulicians was, that the friction was entirely unaffected by the condition of the interior of the pipe, whether as smooth as glass, or of the average roughness of cast-iron pipes; consequently, when 25 oz. is stated as the friction per foot of surface, at a velocity of 15 feet per second, with the absence of additional light upon the subject, that amount of friction had to be regarded as a constant quantity; and, if the analogy between exterior and interior surfaces were complete, such exterior surfaces ought logically to have been no more affected by roughness than interior surfaces; a conclusion contrary to the result of all experience.

Comparatively recent experiments in France, carefully conducted by M. Henry Darcy,[2] Inspecteur des Ponts et Chausées, appear to show, however, that contrary to the general belief, the condition of the surface of pipes modifies the resistance considerably. With three different conditions of surface, the following coefficients of resistance were obtained:—

A. Iron plate covered with bitumen made very smooth	0·000432
B. New cast iron	0·000584
C. Cast iron covered with deposit . . .	0·001167

The friction varied, therefore, nearly in the proportion of 1, $1\frac{1}{2}$, and 3 respectively. Hence, if the above experiments are correct,

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[1] If in sea water, this would be 6·42 lbs., the H.P. = 4,552, and the excess 1,131, H.P.

[2] *Vide* "Hydraulique," par Arthur Morin, p. 164, Paris, 1858.

which there appears no reason to doubt, it is clear that the 25 oz. previously spoken of at 15 feet per second could no longer be regarded as a fixed quantity applicable to all conditions of the surface, although probably high enough to include the usual amount of roughness practically met with in pipes. From the Author's calculations, it appears to come in, in the above scale, intermediately between *B* and *C*. At 15 feet per second, *A* would give $13\frac{1}{3}$ oz., *B* 20 oz., and *C* 40 oz. of friction per square foot.

Independently, however, of these views of M. Darcy, there is another cause for the excess of friction in pipes and water courses, over that on exterior surfaces, which, as far as the Author is aware, has hitherto escaped observation. It arises from the circumstance, that the calculations usually employed for obtaining the friction in pipes and water courses, are based upon the average velocity of the fluid; whilst, it is the surface or maximum velocity which has to be dealt with, when comparing the resulting friction of water courses and moving bodies [1] (Plate 6, Figs. 9 and 10). Thus, if the case of a water course be taken, where the width is so great, in proportion to the depth, as to admit of neglecting the friction of the sides; with an average velocity of 15 feet per second, the friction upon the bottom will be 25 oz. per square foot. According to the usual rules, however, an average velocity of 15 feet per second, corresponds to a surface velocity of 16·66 feet per second, which is the velocity of a vessel passing through still water with which the comparison ought to be made. Consequently, if the velocity of the vessel be 15 feet per second, or only equal to the average velocity in the pipe, the friction of the vessel should be to that of the pipe 15′ to 16·66′, or as 1 to 1·23 only. Beaufoy's experiments give the friction per square foot of a painted plank at 16·66 feet per second, equal to 14·91 oz., taking which from

[1] When an exterior surface, like that of a ship, passes through a mass of surrounding water at rest, the friction of the surface puts into motion a certain quantity of the fluid, which extends for some distance away from the moving surface beyond which it remains at rest; the velocity being greatest immediately adjacent to the moving surface, and gradually diminishing to nothing at the distance from it above alluded to. Suppose the action to be reversed, that a wide extent of water is already in the same velocity of uniform motion as the vessel above referred to, now supposed to be securely moored. It is concluded that the same amount of friction as before will be developed against the surface of the vessel, which will now require as much force to hold it back as in the former case was required to draw it through the water. The action upon a certain breadth of water, taken, as before, a certain distance from the vessel, will now be to leave the outer filaments with their original velocity, whilst all the others will be more and more retarded, in proportion as the side of the vessel is approached.

If this view be correct, there is a perfect identity between the case of the sides of a ship thus acted upon and the bottom of a water course wherein the surface velocity is equal to the uniform velocity of the mass of water around the vessel. But the hypothesis upon which is founded the assertion of the equality of friction on exterior and interior surfaces takes the mean or average velocity of the fluid in the water course to contrast with the surface velocity in the case of the ship, and, therefore, gives too high a coefficient in the case of the water course.—G. H. P.

25 oz., the friction in the pipe, leaves 10·09 oz.; a quantity which appears to be referable to the greater smoothness of the plank.

Taking, as above, the measure of friction on the surface of a new iron ship, when moving at a speed of 30 feet per second, at 4·26 lbs. per foot, it will be found that this resistance is equal to the $\frac{1}{211{\cdot}13}$th part of that to which a plane surface 1 foot square would be exposed on its forward side, when moving at right angles to itself at the same velocity. Both planes also being subject to the same law of increased resistance, according to the square of the velocities, nearly, the same constant ratio of 1 to 211·13 will subsist at all velocities. The ratio is as $\frac{64{\cdot}2\ v^2}{2\ g}$ to 4·26 lbs. = $\frac{1}{211{\cdot}13}$.[1] Calling the ratio r, and the whole frictional surface in square feet s, and S, as before, the surface of an equivalent square plane, then $S = s \div r$, or $S = s \div 211{\cdot}13$.

It now only remains to apply the foregoing calculations to some particular case, for which the steam ship 'Leinster,' previously mentioned, has been selected as an example. The following are such part of the dimensions and proportions of the vessel as are requisite for the present inquiry; namely, the resistance of the vessel at a velocity of 30 feet per second in sea water, as on her trial trip:—

m, the area of the immersed midship section	336 sq. feet.
d, the draught of water	13 feet.
r, the reduced ratio of the slant length of the bow to the projection	10 to 1
r', the same for the stern	10 to 1
r'', the ratio of 1 square foot of direct pressure to 1 square foot of frictional surface	211·13 to 1
v, the velocity in feet per second	30
w, the weight of 1 cubic foot of sea water	64·2 lbs.
f, the frictional surface	13,000 sq. feet

[1] The following coefficients of friction may be taken as nearly correct:—

	Ratio of Friction to a square-acting plane.	Friction at 15 Feet per Second.
Perfectly new well-painted iron plate	$\frac{1}{211{\cdot}13}$	1·065 lb. per foot.
Beaufoy's planed and painted plank.	$\frac{1}{280{\cdot}3}$	0·763 ,,
Ship's coppering, from the 'Rattler,' not exceeding	$\frac{1}{367}$	0·710 ,,

Calling the various resistances in sea water as follows:—

P, the Plus, or Head Resistance.
M, the Minus, or Stern Resistance.
F, the Frictional, or Surface Resistance.
A, the Additional Head Resistance.
R, the Total Resistance.
S, as before, the area of a square plane having equal resistance with each of the above.

Square Feet.

Then $P = \frac{m}{r^2} = S = 336 \div 100 =$ 3·36

$M = \frac{m}{r^2} = S = 336 \div 100 =$ 3·36

$F = \frac{13000}{211{\cdot}13} = S =$ 61·10

$A = \frac{2 \times 0{\cdot}5 \times 13}{7} = S = 13 \div 7 =$ 1·86

$S =$ 69·68

Then $R = 69{\cdot}68 \times \frac{64{\cdot}2v^2}{2g} = 69{\cdot}68 \times 900 = 62712$ lbs.

lbs. ft. per sec.

H (Realized Power) $= 62712 \times 30 \div 550 = 3420{\cdot}66$ H.P.

H', Gross Power, including slip, and other losses

$= 3420{\cdot}66 \times \frac{100}{72} = 4751$ H.P.

From the above it will be seen, that by ascertaining the value of S, for any vessel, which is entirely independent of velocity, it will be easy to determine the power to propel it at any required speed, or, the speed at which any given power can propel the same vessel.

Generally, $$H = VS \times \frac{64{\cdot}2v^2}{2g} \div 550 \quad . \quad . \quad . \quad . \quad (1)$$

Or, because for sea water 64·2 is very nearly equal to $2g$,

$$H = \frac{V^3 S}{550} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

When the slip, and other losses, are in the same proportion as the above,

$$H'^{(1)} = H \frac{100}{72} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

When the Gross Power is given, and the velocity is required,

$$V = \left(\frac{H^{(2)} \frac{72}{100} \times 550}{S \frac{64{\cdot}2}{2g}} \right)^{\frac{1}{3}} \quad . \quad . \quad . \quad . \quad (4)$$

A few remarks, founded upon these calculations, will now be offered, upon the influence of form in reducing the resistance of vessels. It appears that in a sharp-built vessel like the 'Leinster,' about $\frac{9}{10}$ths of the whole resistance is due to friction of the surface, leaving $\frac{1}{10}$th only as assignable to Inertial Resistance, or that part which alone seems referable to the influence of form. Thus, from this reasoning, it would appear, as if no improvement of moment could be made, by any slight modification in the form of the vessel's bow, or 'run.' The same observation will also apply to other vessels constructed on ordinary good lines. If, for instance, a vessel, whose inertial resistance is to the total resistance as 1 to 5, and proportion of average slant length of bow to base as 6 to 1, were to have the inclination of the bow improved up to $8\frac{1}{2}$ to 1, the effect of this alteration would only be to reduce the total resistance by $\frac{1}{10}$th.

It is right, however, to state, that various practical results have been brought forward, at different times, to show that the advantage to be derived from moderate changes in a vessel's form are greatly in excess of the above, an opinion believed by the Author to be fallacious, and to be traceable to the means by which the supposed resistances of the vessels have been arrived at, as will be presently explained. The instances alluded to are, with the exception of the 'Dwarf,' given in the discussion upon Mr. Armstrong's paper "On High Speed Steam Navigation,"[3] and are as follows:—

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[1] If in fresh water, $H' \times 0{\cdot}97 =$ the Gross Horse Power.
[2] If in fresh water $V \div 0{\cdot}99 =$ the Velocity.
[3] *Vide* Minutes of Proceedings Inst. C. E., vol. xvi., p. 331 *et seq.*

No. 1.—H.M.S. 'Rifleman' (Screw)

By improvement in stern lines—	Knots.	Ind. H.P.
Original condition	8·09	348
Altered condition	9·50	367
Ditto ditto	8·01	188

No. 2.—H.M.S. 'Teazer' (Screw).

By improvement in stern lines—		
Original condition	6·31	17
Altered condition	7·68	12

No. 3.—H.M.S 'Dwarf'[1] (Screw).

Experimented upon by lining up the 'run' with three layers of planks, each 3 inches thick, and afterwards removing the same.

Original condition	9·1	The same engines.
When lined up	3 25	

In the original condition the engines made 32 revolutions per minute, with 30·4 per cent. slip of screw, and after the alteration only 24 revolutions; the slip must, therefore, in the latter case, have been about 60 per cent.

No. 4.—Ship 'Magnet.'

By altering angle of bow from 42° to 23°—		
Original condition	11·02	Power not stated, but considered equal.
Altered condition	11·75	

No. 5.—H.M.S. 'Flying Fish' (Screw).

By adding new bow, 18 feet in advance of original—		
Original condition	11·73	1,166
Altered condition	12·55	1,266

	Length.	Draught.	Area of Middle Section.	
	Feet.	Ft. In.	Sq. Feet.	
No. 6.—Vessel by Mr. Scott Russell	190	6 8	124	15·03
No. 7.—Ditto, ditto	186	2 10	71	11·32

The breadth of both vessels was the same. The engines were stated to have been of similar power, and to have made the same number of revolutions per minute.

An examination of these cases has convinced the Author of the futility of attempting to derive any useful general conclusions from

[1] *Vide* Bourne "On the Screw Propeller," pp. 134, 135, 240, and 241. London, 1852.

them. The apparently large diminution of resistance in some of the vessels, by comparatively minute alterations, seems quite unaccountable by any of the usual methods of examining the question. For instance, in the 'Dwarf,' a vessel 130 feet long, 16 feet beam, 6 feet 5 inches mean draught, originally with a fine 'run,' how is it possible that the mere lining up of the 'run,' with 9 inches of material nicely tapered off, should have the effect of reducing the speed, with the same engines, from 9·1 knots to 3·25 knots per hour, when, in the well-known experiment with the 'Rattler,' and 'Alecto,' vessels exactly similar, and therefore of similar resistance, the 'Rattler' towed the 'Alecto' at a speed of about 7 knots per hour, the speed of the 'Rattler,' without any resistance but her own having previously only reached about 10 knots? Here, with a double resistance, the speed attained is $\frac{7}{10}$ths, whilst in the case of the 'Dwarf,' the speed is reduced to about $\frac{1}{3}$rd, by the addition of a comparatively very small obstruction. There appears little reason to doubt, that the anomalous character of the facts exhibited by these examples, is traceable to the use of the Screw Propeller as a test of the resistance of the vessels. This instrument possesses the property of adding to the resistance intended to be overcome, for under certain relations of the magnitude, &c., of the screws to the resistance of the vessel, the slip becomes enormously great, and so much water is abstracted by this means from the after-end of the vessel, as greatly to neutralize, by minus pressure, the effect of the thrust on the screw shaft (Plate 6, Fig. 11).[1] In one of the experiments on the 'Dwarf,' a pressure of 0·837 ton only on the screw shaft gave a speed of 9·049 knots; whilst, with 1·81 ton, the speed was only 7·94 knots: but in the first experiment the slip was 36·3 per cent., and in the other 49·35 per cent. The Author has, therefore, arrived at the opinion, that the true Resistance of Vessels can never be properly determined from the speed produced by the Screw Propeller; and that a very different value of the Resistance would, in all probability, be obtained, could it be measured by the direct strain upon a towing-rope.

In conclusion, the Author earnestly hopes that the views here expressed, upon the Resistance to Bodies passing through Water, may lead to an interesting discussion, and to the expression of the opinions of Members of the Institution, so many of whom are much better qualified than himself to throw light upon this interesting and important subject.

The communication is accompanied by a series of diagrams, from which Plates 5 and 6 have been compiled.

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[1] *Vide* Bourne "On the Screw-Propeller," p. 139.

APPENDIX.

I. Description of the Figures, Plates 5 and 6.

Figs. 1 and 2 are intended to show the action of a square plane when drawn through the water. If A B is the distance through which the plane is drawn in any short space of time, and expresses also the distance to which the pressure is propagated in advance, the fluid may be supposed to escape laterally, with speeds commensurate with the ordinates C D, E F, &c, of the curve D F G. Thus, I H G C, becomes emptied at a less speed than shown by the line A B. On Fig. 2 the shaded portion represents the lateral escape, which being in proportion to the perimeter K L M N, whilst the quantity of fluid to be displaced is as the area, it follows that the larger the plane, the greater will be the proportionate resistance.

Figs. 3 and 4 are intended to show the manner of calculating the resistance of inclined planes, where E F is the inclined plane, and A B C D its projection. Then the resistance of the inclined plane is to that of the projection as the squares of their areas.

Figs. 5 and 6 are intended to show the effect of the increased head resistance. Suppose A B, A C, A D, &c., to show the inclinations of various planes in such manner as making A B = unity, the other inclinations shall be as 2 A B, 3 A B, &c., then the theoretical resistances will be as A B divided by the squares of the above lengths, or $\frac{1}{1}$, $\frac{1}{4}$, $\frac{1}{9}$, $\frac{1}{16}$, &c. In Fig. 6, the heights C c, D d, F f, &c., are plotted in proportion to the above resistances, and the distances C h, D i, F k, &c., are all equal, namely to $\frac{1}{7}$ of A a. The total heights $c\,h$, $d\,i$, $e\,k$, &c., then show the whole resistance for each inclination; but however long any inclined plane might be, this increase is not supposed to operate beyond a sine of the angle equal to A B = 6 inches.

Fig. 7, is intended to show the method of dealing with a curved surface, by dividing it into the straight portions A B, B D, &c., and then dealing with each according to the squares of their lengths A B, and projections B C. It is worthy of remark, that although, theoretically, a straight plane all the way from A to H gives the least resistance, the curved forms practically always resist less.

Fig. 8, shows the result of an experiment, by Mr. Colthurst, for the purpose of ascertaining the proportionate increase of the resistance on an angular prow, A B C, when increased to double the width, A D E. The width B C was $8\frac{1}{2}$ inches, and D E 17 inches. At a speed of 4·96 feet per second, making proper deductions for friction and minus pressure, the resistances were nearly as 3 to 4 instead of 3 to 6; thus supporting the Author's theory of the larger resistance upon the forward portion of the plane.

Figs. 9 and 10 illustrate the Author's view of the difference to be expected in the friction of water upon internal and external surfaces when of equal smoothness. In Fig. 9, A B C D represents a longitudinal section of a watercourse of unlimited width, so as to make the hydraulic mean depth equal to the depth, A D, of the fluid. Since all the filaments from G to I move with continually diminishing velocities, G H, I K, some one filament, E F, moves with the average speed of all; and this is called, in general language, the speed of the water in the watercourse. Let L M, Fig. 10, be the side of a vessel moored in an open river, the water in which flows down on the line N D, at the same speed as the filament E F (Fig. 9). This speed is what is meant by the expression, the speed of the vessel through the river. The diagram L M N O is in all respects similar to A B C D, except that the speed of the filament E F is equal to that of O N; hence a greater speed must necessarily exist at I K than at R S, and consequently, a greater friction.

Fig. 11 is intended to represent the screw, and a portion of the stern, of H.M.S. 'Rattler,' for the purpose of showing the effect of the slip of the screw, in retarding the vessel, by increasing the minus resistance. The currents B C and D E are abstracting water from the vessel's run, and immersing the resistance, so that (particularly when the vessel is moving slowly, and the slip is considerable) the pressure at A, of the screw shaft, exceeds the true resistance of the vessel by a very large quantity.

II. Data upon which the Calculation of the Resistance of the Royal West India Mail Steam Ship 'Atrato,' on her trial trip, was based.

		Square Feet.	
m. Area of midship section		539	
r. Reduced ratio of slant length of bow to projection		6·7 to 1	
r'. Ditto, ditto, stern		6·7 to 1	
r''. Ratio of resistance of 1 square foot of frictional surface to 1 square foot of square acting surface		1 to 211·13	
		Knots.	
v. Velocity in feet per second		23·27 =	13·77
		Feet.	
d. Draught of water		$16\frac{1}{3}$	
		Square Feet.	
s. Frictional surface		15·12	

Resistance in equivalent areas of square acting surface.

		Square Feet.
P = Plus resistance	$= \frac{m}{r^2}$	= 12·00
A = Additional head resistance	$= \frac{16 \cdot 33}{r}$	= 2·33
M = Minus resistance	$= \frac{m}{r^2}$	= 12·00
F = Frictional resistance	$= \frac{15912}{211 \cdot 13}$	= 75·36
Total square acting surface		101·69 = S.

		lbs.	
Then R. Total resistance	$= 101 \cdot 8 \times \frac{64 \cdot 2\, v^2}{2\, g}$	=	55124·5
		H. P.	
H. Realised power	$= \frac{55124 \cdot 5 \times 23 \cdot 27}{550}$	=	2,332
H¹. Gross power. Slip being $\frac{1}{4}$th, and friction, &c. $\frac{1}{10}$th	$= 2332 \times \frac{40}{27}$	=	3,455

	H. P.
Net power by the Author's method	2,332
Gross Power by ditto ditto	3,455
Indicated horse power	3,046
Net power by Mr. Hawksley's formula	2,806
Gross power by ditto ditto, if increased in the foregoing proportion of $\frac{40}{27}$	4,157

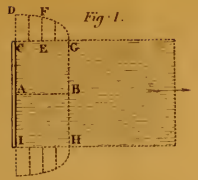
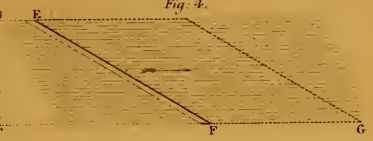


Fig: 1.

Fig: 2.

Fig: 3.



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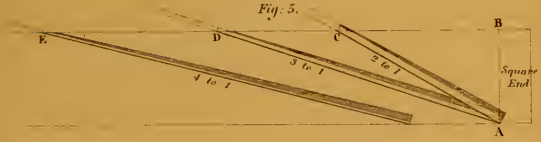

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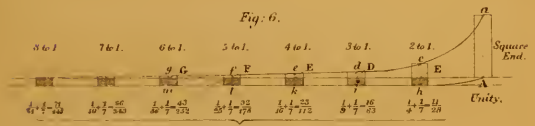


Fig: 6.

Proportionate Resistances taking Square end as Unity.

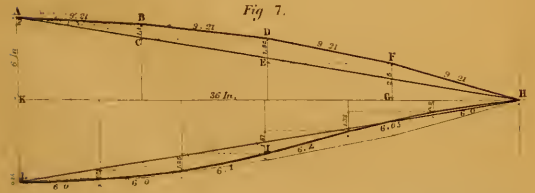


Fig 7.

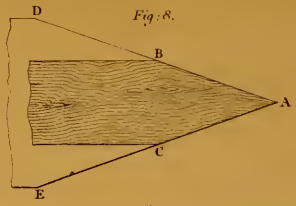


Fig: 8.

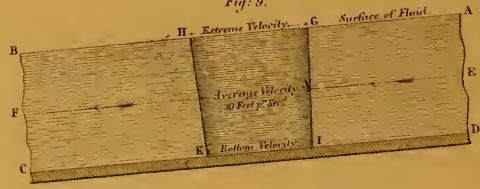


Fig: 9.

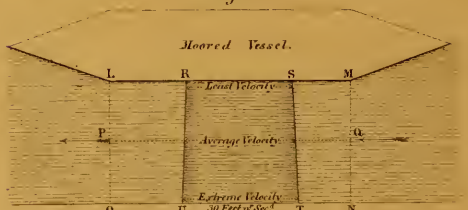


Fig: 10.

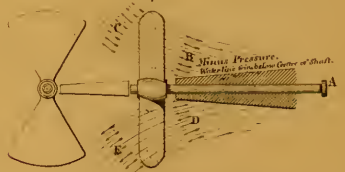


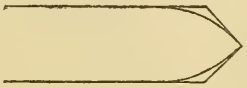
Fig: 11.

Screw and Stern of the 'Rattler'.

III. Experiments (referred to at page 349) on the Resistance to Motion, due to the Form of Floating Bodies. By Joseph Colthurst, M. Inst. C.E.

Form.	Resistance per Foot of Midship Section (freed from the friction of the wetted surface) at a speed of one Statute Mile per hour.	Proportional Resistance, assuming that of the Square End to be unity.
	lbs.	lbs.
Square at both ends	2·28	1·000
Semicircular at ditto	0·99	0·434
Angle 90° at ditto.	0·76	0·333
Ditto 70° at ditto.	0·64	0·280
Ditto 50° at ditto.	0·31	0·136
Ditto 30° at ditto.	0·20	0·088
Ditto 20° at ditto.	0·12	0·056

The models were all flat-bottomed, of the same length, and similar at both ends.

The angles of entrance and at the stern were rounded off as they joined the sides, thus 

The rounding off of angle 20° extended to the midship section.

The friction of the wetted surface was deducted in each case, and was ascertained to amount to 0·01 lb. per foot at a speed of one mile per hour—the surface being planed.

The above results form part of a series which includes various other forms.

IV. Experiments on the Resistance to Motion of Floating Bodies due to the Friction of the Wetted Surface. By Joseph Colthurst, M. Inst. C.E.

Surface.	Resistance per Foot of Wetted Surface at a Velocity of One Statute Mile per Hour, in Fresh Water.
	lb.
Sawn wood	·014
Planed ditto	·010
Ditto, and painted with red lead	·010
Ditto ditto and covered with imitation sea-grass	0·47
Ditto ditto ditto with imitation barnacles	0·56

Sea-grass was imitated by hemp, 4½ inches long, attached to the sides of a friction board, and barnacles by the deep side of small oyster-shells tacked on, convex side outwards, at the rate of three per superficial foot.

[Mr. Phipps

Mr. PHIPPS said, since the Paper was written, he had, through the courtesy of Mr. Marshall, of the Royal West India Mail Company, been permitted to have access to the drawings of that Company's ship the 'Atrato,' as well as to the particulars of the power of the engines, and speed attained on the trial trip of that vessel. He had considered it important to obtain reliable data concerning the 'Atrato' for two reasons; first, because this vessel had been taken as an example in support of a method of calculating resistance;[1] and secondly, because she was a vessel of totally different type from the 'Leinster,' on the particulars of which the calculations in the Paper were chiefly based. The proportions of the vessel and other data given on a previous occasion were widely different from the results he had obtained from the drawings, and particularly so in respect to the amount of wetted surface, which exceeded the estimate referred to by more than 3,000 square feet. The data relating to the 'Atrato' on the trial trip were:—

Length	315	feet
Breadth	42	„
Draught of water	16·4	„
Indicated horse power	3,046	
Area of immersed midship section	539	square feet.
Area of wetted surface	15,912	„
Speed 13·77 knots per hour = 13·77		feet per second.
Slip of paddle	25	per cent.

Taking from the above indicated H.P. $\frac{1}{10}$th for friction, working air-pumps, &c., and 25 per cent. of the remainder for the slip of the paddles, there remained a net amount of 2,053½ H.P. as applicable to overcoming the resistance of the vessel. By his method of calculation, the net power required was 2,226 H.P., or 172½ H.P. in excess of the above; whilst by the method previously given in the Minutes of Proceedings, the excess became 752½ H.P., or more than four times as much. The difference was mainly attributable to the very high coefficient for friction, which, it would be remembered, had been derived from experiments upon the flow of water through pipes. An elaborate course of experiments, upon the frictional and other resistances of floating bodies, had been conducted by Mr. Colthurst, and the result of one of those experiments was confirmatory of the views expressed in the Paper, as to the much higher value of the pressure encountered by any unit of surface situated upon the foremost portion of an inclined plane, of limited extent, in its passage through water, than on

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xvi., p. 357.

a similar unit on the after part of the plane; a view which he believed was also fully confirmed by the known fact of the inutility of increasing, beyond a very limited extent, the acting surface of a screw propeller. In Mr. Colthurst's experiment, two bodies were drawn through the water at the same speed of 4·96 feet per second. They were furnished with angular prows of the same inclination, with proportion of base to slant length as 1 to 3·3, but one was constructed of exactly twice the width of the other, and being immersed to the same depth, $4\frac{1}{2}$ inches, the latter presented double the surface in contact with water. By the experiment it was proved, that the comparative resistances were as 1·89 to 2·51, or nearly as 3 to 4, instead of 3 to 6, which would have been the result had the resistance been equal on each unit of surface throughout the extent of the prow.

Mr. J. M. Heppel said, whatever might be the opinion of the Members with regard to the theoretical views advanced in the Paper, all must agree that a very valuable collection of data had been contributed to the Minutes of Proceedings. It appeared from the statements in the Paper, that the value of frictional resistance, as deduced from the flow of water through pipes, if applied to the case of vessels moving in water, would in some instances bring the amount of this resistance to more than sufficient to absorb the whole indicated H.P. of the vessel. That would lead to the belief that, in the case of a vessel going through water, there was something different in the frictional resistance to that which obtained in pipes through which water was flowing. There was nothing surprising in such a result, when it was considered that the conditions of a vessel moving through a large expanse of water were not exactly analogous to the case of water flowing through pipes, or as it was called, 'in train.' There was one condition of the motion of water in pipes which was wanting altogether in that of vessels; if, for instance, the section of a pipe 'in train' in any one place were taken, and another of the same pipe at some distance from the first section, there was no reason why the condition of the water at one section should differ from that at the other. In the case of a vessel moving through water this did not obtain. In a long vessel, putting aside the stern and bow, and taking only that part which was pretty nearly equal to the midship section, the conditions of the water passing the section near the bow were not necessarily the same with those of the water passing near the stern. It was conceivable that they might be entirely different. He believed that, whereas the velocity of the water passing through pipes 'in train' had been well ascertained, the actual velocity of the water in contact with the surface of a vessel had not yet been determined. The velocity of the vessel, in reference to a fixed point, was known; but there was

no means of deducing the actual velocity of the water in contact with the surface of the vessel. He thought the Author had logically and correctly deduced, that the whole frictional resistance of the vessel could not exceed a certain amount ascertainable by means of the indicated H.P.

Mr. ARMSTRONG said, the Author had adopted the only scientific method of investigating the problem of the resistance of floating bodies, by taking, as a basis, a vessel with a square head. The only path for the solution of the problem was to establish a general proposition, similar to the principle of the celebrated D'Alembert, for resolving the hitherto difficult dynamic problem which was under discussion. The question briefly was, whether the mechanical effect of forces, or a pressure of steam, was a constant or a variable quantity? In working out this problem, it was to be regretted that experiments, as to the towing of variously formed vessels at various velocities had not been made by the British Admiralty, for experiments of that character would have afforded abundant proof, that the resistance of bodies in a fluid did not vary as the square of the velocity. But, even without those experiments, it might be affirmed, that the data already given by the Admiralty contained all the elements necessary to the mathematician for the inductive solution of the theory of fluid resistance.

In the following table were given the data connected with the trials of the 'Flying Fish,' 'Victor,' and 'Pioneer.' They were selected to exhibit the variable amounts of indicated H.P., and the constant quantities of pressure in the cylinders for an equal speed of vessel.

NAME OF VESSEL.	No. of Experiment.	$\frac{V^3 \times \text{Mid. Sect.}}{\text{I. H.P.}}$	Velocity in Knots.	I. H.P.	Midship Section.	Velocity in Feet per Second.	Average Pressure on Cylinders.	$\frac{A\ Vel.^2}{\text{Feet per Second.}}$	$\frac{A\ Vel.^2}{\text{Average Pressure.}}$	Velocity of Piston in Feet per Second.
'Flying Fish' (July 3, 1856).	4	469	9·92	576	277	16·76	68,791	77,837	1·12	4·61
,, ,,	5	443	11·20	877	277	18·92	94,305	99,792	1·04	5·12
,, ,,	6	411	11·47	1,016	277	19·26	103,512	102,767	·98	5·40
,, ,,	3	376	11·73	1,166	272	19·77	114,188	106,352	·96	5·02
,, ,,	7	372	11·60	1,160	277	19·60	114,400	106,368	·96	5·58
,, ,,	2	341	11·29	1,154	274	19·09	106,576	100,010	·94	5·96
,, ,,	1	335	11·58	1,302	281	19·43	116,466	106,218	·94	6·15
'Victor'	1	351	11·58	1,165	264	19·43	93,886	99,792	1·06	6·83
'Pioneer'	1	336	11·36	1,192	273	19·09	95,988	99,645	1·02	6·83

The vessels were identical in dimensions, form, amount of H.P., and in the description of propeller; and, moreover, four of

the trials of the 'Flying Fish' were made on the same day. The coefficients for those four trials—4th, 5th, 6th, 7th, were respectively 469, 443, 411, and 372, or a variation of 25 per cent. On comparing the fifth with the seventh trial, it was found that in the former case 877 I.H.P. was required to obtain a speed of 11·2 knots, and in the latter case 1,160 I.H.P. was required to obtain a speed of 11·6 knots, or an increase of power somewhat about 50 per cent. He would ask whether it was possible that any formula could meet such an anomaly? It must be conceded, that in these tabulated trials the cause of the variation in the coefficients existed in the indicated H.P. If the first and last column were examined, it would be found that as the coefficient diminished, the velocity of the piston increased. The same fact was exhibited six times by the 'Flying Fish,' in 1861, and in a perusal of the whole of the published data given by the Admiralty, for instance, the

	Coefficient.	Velocity of Piston.
'Rattler' .	676	3·60 feet per second.
'Desperate'	697	2·51 ,,
'Cruiser' .	727	3·42 ,,
'Simoom'	688	4·37 ,,
'Miranda'	680	3·56 ,,
'Algiers' .	687	2·91 ,,
'Russell' .	394	8·12 ,,
'Cornwallis'	342	8·58 ,,

Although it might appear to be proceeding tentatively with those experiments, he would state what were the axioms of the conservation of the mechanical effects of force which he had adopted. First, with respect to the steam-engine, he asserted that the mechanical effect was only proportional to the pressure in the cylinders—not to the "force and space passed over," or, correctly speaking, that the pressure in the cylinders was properly the power of the engine. Applied to the theory of fluid resistance, he asserted that the work done was proportional to the motive weights expressed by Colonel Beaufoy's formula, viz. Force = AV^2, consequently, the resistance could only be as the simple speed; and with respect to diminishing that quantity, he had the authority of Sir Isaac Newton's Principia for stating, that it was impossible of diminution by any form, however pointed. He fully expected to hear that this theory only applied to bodies deeply immersed. If it was to be applied to bodies floating on the surface, according to Sir Isaac Newton's rules, it would be necessary to add a small amount to Beaufoy's quantities. To apply this theory to actual practice, the area of the midship section should be multiplied by the velocity in feet per second squared, or, in other words, $F = AV^2$

was the theoretical amount of pressure in pounds required in the cylinder of the steam-engine. That quantity could not be diminished by any alteration in the velocity of the piston. In the tabulation there was a variation of 50 per cent. in the velocity of the piston, with scarcely any variation in the actual pressure from the theoretical amount. What little variation did exist was in the wrong direction for the present theory of the steam-engine. He would remind the members that these experiments only practically established the amount of pressure required. The theoretical question remained, what was the actual amount of work performed, or the mechanical equivalent of a unit pressure of steam? To arrive at that quantity, he would again refer to Beaufoy's experiments, the results deduced from which might be expressed as follows :—

Motive Weights.	Area.	Velocity.
1	1 square foot.	1 foot per second.
4	1 „	2 „
9	1 „	3 „
16	1 „	4 „

The primary results were not denied; but he could not admit that the resistance was equal to the motive weight at rest. If the resistance were equal, then there was a weight of matter producing a variable amount of mechanical effect. Such a theory was repugnant to all inductive reasoning. It had always been conceded that the resistance of bodies in a fluid was one power below the propelling power. Now, if the pressure in the cylinders was the power of the engine, and varied as the square of the velocity, the resistance must be as the speed. But until experiments were tried to confirm that principle, he must be content to produce the only dynamometer experiments with which he was acquainted—namely, those made on board the 'Rattler.' Those experiments, so far as they could be relied upon, proved that the thrust only varied as the speed.

			lbs.
April 1st, 1845,	10 knots		9,463
„ 3rd „	$8\frac{1}{4}$ „	no wind	6,243
„ „ „	4 „	„	4,751
„ 8th „	$8\frac{1}{2}$ „	4 points on starboard bow	7,997

In the first of those experiments, the actual power exerted by the engines was 369 indicated H.P., and that of the shaft 290, as taken by the dynamometer for a speed of 10 knots. Therefore assuming, as stated by the Author, that 170 H.P. was due to the friction on the immersed surface of that vessel, 120 actual H.P. would only be left for propelling the 'Rattler' 10 knots per hour.

Mr. J. Scott Russell said, having been engaged in similar

investigations, he had found that an enormous mass of experiments had been made on the subject, almost without method, no two sets being under similar circumstances, and very few under the circumstances to which it was endeavoured to apply the results deduced from them. One-half, perhaps he might say two-thirds, of the experiments upon the resistance of water to bodies passing through it, which were said to have been undertaken for the purposes of naval architecture and for throwing light upon the construction of ships, had actually been performed under water, as if it had been the business of the naval architect to make fishes instead of ships. There was practically little analogy between a vessel floating on the surface of the water and dragged along it, and the same vessel sunk in and moving through the water.

The first fixed principle which the Author thought might be adopted for ships was to assume, as was done in many other branches of engineering, as the measure of the head resistance to a square-ended body dragged through the water, the pressure of the head of water, or the pressure of a column of water raised to the height due to gravity by the velocity of the vessel. He approved of that measure; and his formula for direct head-pressure per square foot was almost similar to that of the Author. For convenience of computation he took 64 lbs. as the weight of a cubic foot of salt water. By adopting this degree of saturation he obtained the simple formula: one pound per square foot, per foot per second as a unit which could be easily remembered, and carrying through the calculation, he found that the resistance of any ship, or of any body dragged through the water was 1 lb. per square foot, per foot per second, in salt water of 64 lbs. to the cubic foot, increasing as the square of the velocity at all speeds.

If it were required from this formula to know what the resistance was, at 20 feet per second, it could be obtained thus—20 feet squared was 400=400 lbs. In the same manner taking 9 feet per second as the velocity, $9 \times 9 = 81$, was the resistance in lbs. He was therefore in accord with the Author, that the measure of head resistance differed only by a minute fraction, and that that difference depended upon the density, or degree of saturation of the water.

As regarded the theory of the resistance of inclined planes, generally known as the theory of the sine squared, and which simply meant, when referred to ships, that with a constant width of vessel made with inclined plane bows, the resistance was as the square of the sine of the angle made by the inclined plane and centre line of the vessel, its truth depended upon the geometrical property involved in the above expression, namely, that the quantity of water removed from the vessel's track in any given time was the same, whatever the angle of the bow, so long as the width

and draught of water remained constant, and that the velocity with which such amount of water was displaced corresponded with the sine of the angle of inclination, and hence the resistance should be as the square of that velocity.

On comparing the theory with the results of experiments made chiefly by Beaufoy, it was found to be true only in the case of the inclination being at an angle of about 45°, while at 6°, 12°, and 15°, the resistance was nearly four times that given by the theory, so that the law of the square of the sine was less and less applicable as the angle of the bow became sharper.

He could confirm these conclusions of the Author by his own examination of the experiments of the French Academicians, which clearly proved that, excepting at about an angle of 45°, the actual resistance always exceeded that of the theory, and all the more so in proportion to the acuteness of the angle.

Summary of Experiments on Angular Wedge-Bows by the Academy of Sciences.

Half-angle Bow.	Direct Resistance.	Column of Unity.	Sines of Angles.	Squares of Sines.	Half-angle of Escape.	Speed of Escape.	Resistance of Escape.	Numbers resulting from Formula by C = 75.
90°	57k·04	1·000	1·000	1·000	90°	$\frac{15}{15}$ $\frac{225}{225}$	1·00	
84	55k·83	0·979	0·995	0·989	96	$\frac{15}{16}$ $\frac{225}{256}$	0·87	
78	54k·58	0·957	0·978	0·957	102	$\frac{15}{17}$ $\frac{225}{289}$	0·77	
72	51k·55	0·904	0·951	0·904	108	$\frac{15}{18}$ $\frac{225}{324}$	0·68	52·1
66	47k·77	0·837	0·914	0·835	114	$\frac{15}{19}$ $\frac{225}{361}$	0·62	46·7
60	53k·99	0·771	0·866	0·75	120	$\frac{15}{20}$ $\frac{225}{400}$	0·56	42·2
54	38k·55	0·676	0·809	0·654	126	$\frac{15}{21}$ $\frac{225}{441}$	0·51	38·3
48	35k·78	0·627	0·743	0·552	132	$\frac{15}{22}$ $\frac{225}{484}$	0·46	34·6
42	31k·53	0·553	0·669	0·448	138	$\frac{15}{23}$ $\frac{225}{529}$	0·42	31·9
36	29k·70	0·521	0·588	0·345	144	$\frac{15}{24}$ $\frac{225}{576}$	0·39	29·3
30	26k·67	0·467	0·5	0·25	150	$\frac{15}{25}$ $\frac{225}{625}$	0·36	27·0
24	23k·77	0·417	0·407	0·165	156	$\frac{15}{26}$ $\frac{225}{676}$	0·33	25·0
18	22k·10	0·387	0·309	0·095	162	$\frac{15}{27}$ $\frac{225}{729}$	0·30	23·1
12	20k·29	0·356	0·208	0·043	168	$\frac{15}{28}$ $\frac{225}{784}$	0·28	21·5
6	19k.39	0·340	0·105	0·011	174	$\frac{15}{29}$ $\frac{225}{841}$	0·26	20·1

With reference to the amount of the resistance of square-ended vessels, he felt assured, both from the experiments of others, and from his own experiments made on various units of square-ended surfaces by means of the instrument known as the "tube of Pitot," up to a speed of 12 miles per hour, that his former statements were correct.

The diminution of resistance due to sharp inclinations of bow arose from the much larger space over which the water displaced by the ship at each instant of time could diffuse itself when the angle was sharp.

If a circle were described from the foremost point of the bow, the resistance of any angle of bow, from a square end, would be as the square of the number of degrees out of the whole 360° left unappropriated by the vessel's bow, and this he termed the angle of escape. This would give for a square end $360° - 180° = 180^2$, and for an angle of 10°, $360° - 10° = 350^2$, these two cases giving resistances as 180^2 to 350^2. The figures arrived at by the above method corresponded in ratio, through a considerable range of angles, with the experiments of the French Academy, although not exactly corresponding with the actual calculated amounts referred to the square end as unity. He agreed in the analogy of the screw propeller and of inclined planes at very acute angles drawn rapidly through the water, and that the enormous pressure developed against the surface of the screw would be equally felt by the bow of a vessel passing at the same angle and speed. He also agreed with the Author that the probability of the pressure only existing for a limited distance along any inclined plane was confirmed by the fact that as much pressure was realized against a screw propeller, as now generally made, where each blade was the $\frac{1}{6}$th part of a convolution only, as where, which was the case in some of the original screws, each blade occupied $\frac{1}{2}$ a convolution. He had no doubt that the power of the rudder in turning a vessel (which was always in excess of the ordinary calculation) was mainly due to the same cause as that adverted to in connection with the screw and much inclined bows. He also thought that the efficiency of the rudder was added to, by the head of water raised above the ordinary level by the resistance of the rudder, and that this head acting laterally against the considerable area of the dead wood of the stern tended very much to increase the effect in turning the vessel; an effect sometimes impaired, however, in screw vessels by the necessary cutting away of a considerable portion of the dead wood, in order to admit the screw propeller.

The properties of water-lines formed with curves of contrary curvature between the cutwater and the midship section—in other words, wave-lines—were very superior to plane surfaces in the facility with which they acted upon and removed the fluid lying in the track of the vessel; the best point of contrary curvature was at one half the distance of the cutwater from the midship section of the vessel. These curved water-lines, when properly formed, acted on the fluid in the same manner as the accelerating force of gravity, the time allowed for acting upon any particular particle of water so as to give it its maximum lateral velocity being the same as that occupied by the passage of the vessel through the distance from the cutwater to the point of contrary curvature. This form of bow therefore was superior to those formed with

plane surfaces, the angle of entrance of which must necessarily be greater.

TABLE showing the Measures of Value of the Hollow Bow or Approximate Wave-line Entrance in diminished Head-Resistance.

Speed in Knots.	Length in Feet.	Beam in Feet.	Bow in Feet.	Values in Diminished Head-Resistance.
10	100	20	60	$(\frac{20}{60})^2 = \frac{1}{9}$
12	144	24	86	$(\frac{24}{86})^2 = \frac{1}{13}$
14	196	28	117	$(\frac{28}{117})^2 = \frac{1}{18}$
16	256	32	153	$(\frac{32}{153})^2 = \frac{1}{23}$
18	324	36	194	$(\frac{36}{194})^2 = \frac{1}{29}$
20	400	40	240	$(\frac{40}{240})^2 = \frac{1}{36}$

With regard to the minus resistance at the stern of a vessel, he could not agree with the Author as to the method adopted for calculating its amount, which method was, in fact, the same as taking the sine of the angle squared as the measure of the resistance. The form and length of a vessel's stern were regulated more by the nature of the wave rising up towards the stern than by the fineness and length of the run, and he had found, by experience, that no advantage accrued from elongating the run one third. He was disposed to think that with the special kind of wave generated by a vessel's bow constructed on the wave principle, the resistance at the stern would be less than that stated in the Paper. The chief question sought to be elucidated in the Paper was that of friction, and there was much pertinence in the remark that the ratio of length to breadth in a ship must not be increased to such an extent as to increase the surface resistance more rapidly than the head and stern resistances were diminished through the influence of form. This limit was clearly dependent upon the amount of friction to which a square foot of wetted surface was exposed, when of the degree of roughness usually met with in practice. According to Beaufoy, whose most valuable experiments were those directed to the friction of surfaces, and were made upon smooth painted planks, 287 feet of frictional surface equalled 1 square foot of direct head resistance. The Author's deductions from the hull of the 'Rattler,' which was copper-bottomed, gave 307 feet, whilst from the iron hull of the 'Leinster,' when on her trial trip, he had deduced 211 feet as the proper measure. Mr. Russell's calculation gave 285 feet for an iron bottom, and he had found that the direct head resistance of a vessel could be reduced from unity for a square end down to $\frac{1}{25}$ by using the wave form of bow, but if

French Academy. Wedge Forms.	Beaufoy.*	Colthurst.†	The Wave Form.	Various.	Coefficients.
∠ 90°	90°	90°	.. .. ..	90°	1·00
		Cylindric ends . . .	.. .. ..	.. .. ..	0·99
72	.. .. ..	.. .. ..	.. .. ..	.. .. ..	0·90
63	.. .. ..	.. .. ..	.. .. ..	.. .. ..	0·80
		∠ 45° with convex arcs.	.. .. ..	.. .. ..	0·76
55	.. .. .	.. .. ..	.. .. ..	Cube; edge in front . .	0·70
		∠ 35° convex arcs . .	.. .. ..	.. .. ..	0·64
44	.. .. ..	.. .. ..	.. .. ..	.. .. ..	0·57
35	.. .. ..	.. .. ..	.. .. ..	.. .. ..	0·51
18	.. .. ..	.. .. ..	.. .. ..	.. .. ..	0·38
	Cylindric bow. . . .	.. .. ..	.. .. ..	.. .. ..	0·37
	Sphere.	.. .. ..	.. .. ..	.. .. ..	0·33
	Cylindric ends . . .	∠ 25° convex arcs . .	.. .. ..	.. .. ..	0·31
6	∠ 30°.	.. .. ..	.. .. ..	.. .. ..	0·30
	∠ 20°.	.. .. ..	.. .. ..	.. .. ..	0·25
	∠ 15°.	.. .. ..	.. .. ..	.. .. ..	0·23
	Spherical ends . . .	.. .. ..	.. .. ..	.. .. ..	0·23
	Sharp cylindric arcs . .	.. .. ..	.. .. ..	.. .. ..	0·23
				Poncelet's (ship-form) .	0·22
	∠ 10°.	∠ 15° convex arcs . .	.. .. ..	Morin's (ship-form) . .	0·20
				Bourgois (whale-boat) .	0·20‡
				Navier's (ship-form) . .	0·18
	Sharpest cylindric arcs .	∠ 10° convex arcs . .	.. .. ..	.. .. ..	0·15
			Wave 5 to 1 form . .	.. .. ..	0·11
				Bourgois (whale-boat) .	0·11‡
			„ 6 to 1 „ . . .	.. .. ..	0·077
			„ 7 to 1 „ . . .	.. .. ..	0·056
			„ 8 to 1 „ . . .	.. .. ..	0·043
			„ 9 to 1 „ . . .	.. .. ..	0·034
			„ 10 to 1 „ . . .	.. .. ..	0·028

* These experiments were made under water, not on the surface.

† Both ends are alike throughout this column.—*Vide ante*, p. 339.

‡ These two results were obtained from the same finely-shaped boat; the less coefficient at a speed less than the speed due to the boat's length, the greater coefficient when that speed was exceeded.

from the effects of dirt, or roughness of the iron plates, the resistance of a vessel were increased in the high proportion indicated by the Author, the advantages of the vessel's fine entrance might very easily be more than counterbalanced by the additional friction thereby introduced.

Mr. ATHERTON said he wished to draw attention to the generally received law, by which present practice was regulated in determining the amount of power by which steamers of any given size might be expected to be propelled at any given speed. He referred to the general rule of arithmetical calculation which was enunciated by the formula $\frac{V^3 D^{\frac{2}{3}}}{P} = C$, C being the coefficient of dynamic performance already determined from the test trials of vessels of the same type of form and surface condition as the new vessel which might be under consideration. The coefficient (C) it would be observed, was deduced from the actual performance of a ship of the same type of form as the new ship to which it was to be applied. For example, supposing that a vessel of 1,000 tons displacement, of which the elementary dimensions of construction were known, were found on trial to be propelled at the speed of 10 knots per hour by 400 indicated H.P., then (by the rule above enunciated) $\frac{10^3 \times 1000^{\frac{2}{3}}}{400} = 250$; and this number would be assigned as the coefficient applicable to any vessel of which the immersed hull might be of the same type, and its condition as to the surface in contact with the water in all respects similar. Having thus experimentally ascertained the value of the coefficient for that particular type of form, the formula $\frac{V^3 D^{\frac{2}{3}}}{H P} = 250$, became applicable to the case in question, and the value of either one of the elements V, D, or P, could be ascertained when the other two were given. Having thus enunciated the rule to which he alluded, and shown its practical application, he would endeavour to explain the theoretical principles upon which it was based. Taking the immersed hull of a ship of any given type of form, and of which the two sides were similar and equal, it was in the first place assumed, that whatever might be the form of the vessel, the direct rectilinear resistance to motion was proportional to the number of molecular units, or particles of water to be removed by the vessel in a unit of time, and the collective force with which they individually acted. Next it was assumed, that the number of such particles to be removed by the vessel in a given time was proportional to the maximum sectional area (A) of the vessel, taken transversely to its line of motion, multiplied by the speed (v) at which the vessel

moved, which might be denoted by Av. Also, that the force with which they individually resisted the motion of the vessel was proportional to the speed (v), and hence, the collective resistance (R) was proportional to $Av \times v$, or Av^2. And as it was an axiom in mechanics, that the power (P) required to overcome any resistance was proportional to the velocity with which it was to be overcome, or moved, it followed that the power (P) required to impel the vessel of which the midship section was A, and of which the resistance was (R), would be proportional to $A\,v^2 \times v$, or $A\,v^3$. Hence it was assumed that, for vessels of different sizes, but of similar types of form, P was proportional to $A\,v^3$, which was mathematically expressed by $P \propto A\,v^3$. But homologous sections of similar bodies were mathematically proportional to the square of the homologous rectilinear dimensions, and the relative cubical capacities (D) of similar bodies (such as the water displacement of similar ships) were proportional to the cubes of the homologous rectilinear dimensions, consequently $A \propto D^{\frac{2}{3}}$; hence, in the above formula $D^{\frac{2}{3}}$ might be substituted for A, and the formula became $P \propto V^3\ D^{\frac{2}{3}}$.

Up to this point he had made no direct mention of the surface (S) of the immersed hull in contact with the water. It was however to be observed that the particles of water acted against this immersed sloping surface of the hull, not in addition to, but in lieu of acting against the midship or maximum section; the effect of such action was modified by the type of form; but, as the surfaces of similar bodies were proportional to the homologous sectional areas, the formula $P \propto V^3\ D^{\frac{2}{3}}$ still held good; consequently $\frac{V^3\ D^{\frac{2}{3}}}{P}$ became a constant number (C) for vessels of the same type, whereof the actual value of C had to be experimentally determined, with reference to any particular type of form to which it might be applied; for, though C might be expected to be a constant number for all vessels of the same type of form, the rule was, that it would vary in different types, and that even in the same type it would be greatly dependent on the condition of the surface of the hull in contact with the water.

It was however to be observed that, as the forms of vessels both forward and aft admitted of infinite changes of type, a good form of forward body might be combined with a bad form of after-body, and vice versâ; and it might thus happen, that vessels of totally dissimilar types of form might possibly produce the same coefficient.

In the construction of the above formula, no notice had, however, been taken of the position of the centre of gravity of the maximum sectional area A, or of the immersed hull of the ship: and that was a point on which, in his opinion, the received formula was open

to further investigation. Admitting therefore that in consequence of the formula taking no cognizance of the centre of gravity of the immersed midship section, or of the water displacement of the ship, it appeared desirable to inquire, how far the application of the formula practically answered the purpose of determining, approximately, the probable capabilities of a new ship of given type, with reference to the mutual relations of displacement, power, and speed. So far as his experience had extended, the practical application of the rule has been satisfactory, and he believed that by its careful application, under the essential conditions on which it was based, namely, similarity of type and surface condition, the capabilities of any new ship, with reference to the mutual relations of its displacement, power, and speed, might be predetermined with remarkable precision.

The performances of the 'Great Eastern,' though never yet fully tested as regarded the capabilities of the ship for the long passage service for which the vessel was specially designed, had on various favourable occasions confirmed the mutual relations of displacement, power, and speed, which were predicated as her probable performances; thereby establishing the general trustworthiness of the formula referred to, as applicable for determining the mutual relations of displacement, power, and speed, which might be expected to be realized by ships up to 25,000 tons of displacement. Although the 'Great Eastern' had thus far beneficially served the cause of theoretical science, it was to be regretted that circumstances had prevented her full capabilities, for making long voyages, as dependent on her surpassing magnitude, from being practically demonstrated.

While on this point he would make a few remarks, on the superior capabilities of large ships as compared with smaller vessels. He assumed the vessels to be all of the same type of form, giving a coefficient $C = 215{\cdot}5$; then, assuming the formula to be applicable, the following results would ensue. First, with reference to speed: the same proportion of power to displacement which drove a ship of 5,000 tons displacement at the speed of 12 knots per hour would drive a ship of 10,000 tons at 13 knots, and a ship of 20,000 tons at 14 knots. Secondly, with reference to power, the speed being given. To attain the speed of 15 knots per hour, a ship of 5,000 tons displacement, of the type under consideration, required 91 indicated horse-power for each 100 tons of displacement; a ship of 10,000 tons displacement required 72 indicated horse-power for each 100 tons of displacement; and a ship of 20,000 tons displacement required only 57 indicated horse-power for each 100 tons of displacement.

It was, however, to be observed, that these advantages of increased size became rapidly neutralized, if on the strength of size

alone, obligations were undertaken which involved an increased rate of speed combined with an increased distance, without recoaling. These matters, however, being duly attended to, it appeared that nautical hazards, port accommodation, and mercantile considerations determined the limits by which the sizes of ships, with reference to their profitable employment, must necessarily be regulated. In a mechanical point of view, irrespectively of nautical, local, and mercantile considerations, the advantages of magnitude appeared to be unquestionable.

Mr. Hawksley, V.P., said, he was perfectly sure that there was no difference whatever between the amount of resistance which water experienced when flowing within a pipe and when flowing without a pipe, and he was certain that the resistance on the external skin of a ship was precisely the same as that in the interior of a pipe when the two surfaces were in the same condition. In illustration, he would suppose, for the moment, that the radius of the pipe was gradually increased till it became infinite. When it became infinite, any small element of the surface was nothing more than a piece of plain plate, or a part of the side of a ship; and when in that condition, it was manifest to any one who had studied the subject under that form, that the friction of the water on the one side of that piece of pipe must be exactly the same as the friction of the water on the other side. But as to the measure of the friction itself, that was another question, and whatever might have been the views of the experimentors, Dubuat, Eytelwein, and Dr. Young, one of the most able of the English philosophers, with regard to the coefficient of the friction being constant and independent of the nature of the surface, and although at one time, believing entirely in their conclusions, he was quite able to admit that some of his own previous ideas on the subject, founded as they were in great measure upon their conclusions, had been erroneous. It had been found, in recent years, that the condition of the surface had very considerably to do with the coefficient of friction. It was perfectly well known, since asphalte had come into use for the prevention of corrosion on the internal surface of pipes, that the friction on an asphalte surface was considerably less than it was on a surface of raw iron. It was also well known, that when the interior surface of an iron pipe was covered with so-called carbuncles, which collected after long use, and especially under the action of soft water, the friction was considerably increased. And while entering upon this subject, he should be glad to be allowed to explain the most modern conclusions with regard to what had been called friction: it was known that if a particle of fluid was flowing down the axis of a pipe, it experienced no resistance whatever, except that which was occasioned by its proceeding faster than the adjoining particles. But by-and-by it

became gradually diverted out of its course, and came in contact with the sides, against which it struck at an angle to its path, and thus lost a part of its preimpressed force: that was not friction at all. It entered into the consideration under the given name of friction, but it was simply force lost by impact, and so followed the ratio of the square of the velocity. But in addition to that, another resistance could also be measured, which was true friction, and that followed the ratio of the first power of the velocity. This latter resistance was very perceptible when the motion was not rapid, but became insensible, and was in a manner merged into the larger measure of resistance, when the motion was considerable.

Putting F for the statical head, which would be in equilibrium with the sum of these two resistances, the formula now generally concurred in by all theoretical writers and practical experimenters became

$$F = a v^2 + b v,$$

a and b being coefficients, to be determined by actual experiment on different materials and different qualities of surfaces.

From this equation, it might be observed, that when the velocity became considerable, the second term practically disappeared; while, on the contrary, when the velocity was fractionally small, the first term practically disappeared. That was a very important consideration, for it seemed to explain some of the many anomalies in the ordinarily accepted formulæ, derived from experiments made upon the resistance of water and gases at widely-varying velocities.

Hence, with respect to a vessel proceeding with a velocity of 10, 20, or 30 feet per second, the value of the first term became very large; whilst the value of the second term was perfectly insignificant. Therefore that term might be omitted, and the friction be considered simply as the square of the velocity, or $F = av^2$. The main question thus became reduced to this, "What was the value of the experimental coefficient (a)?" Upon that point, in which he differed in part from and in part agreed with the Author, the experiments of Colonel Beaufoy had been quoted. Now Mr. Hawksley was sorry to say that he, in common with many other persons, who had had a good deal to do with hydraulic subjects, did not entertain a very high opinion of the results obtained by Colonel Beaufoy. Those experiments were no doubt honestly and intelligently made; but Colonel Beaufoy did not conduct his experiments on friction so as to eliminate from his results the many sources of error by which they were affected. Colonel Beaufoy mixed up together a number of large resistances, of which friction formed only a small portion;

and, in consequence, it was impossible to establish an equation for friction only, by means of which any practical result could be deduced from his experiments. In point of fact, in all his great book there were only one or two pages which were of the smallest possible value for the purpose, and in these, the stated results were not only conflicting, but were derived from surfaces not at all analogous to that of an iron sea-going vessel. He was sorry to express himself in these terms with regard to experiments, the importance of which he thought had been estimated by the magnificence of the book, and the great liberality of its laborious author. He had the highest personal respect for Colonel Beaufoy. Every one who knew anything of the cost and difficulty of experimenting on hydraulics must have respect for him; but having respect for him, and having respect for his results, were two very different things. The Author had particularly quoted the portion of those experiments relating to the resistance to a piece of wood of a particular form, well painted, or varnished, made very smooth, and almost polished. Admitting the accuracy of Colonel Beaufoy's experiment, Mr. Hawksley disputed its applicability to the purposes for which the Author had appropriated it. The condition of the outside of a vessel in actual use, and not upon a trial trip, when she came out very nicely finished from the hands of the builder and painter, was very different from that under which Colonel Beaufoy's experiments were made. Colonel Beaufoy, he believed, under the circumstances mentioned, got a resistance so small that it amounted to less than one-half that which a ship actually sustained when working a voyage under ordinary circumstances. Now, so long ago as the year 1856, Mr. Hawksley was at a good deal of pains on this subject; because it so happened at that time the Institution was taking a strong interest in the subject which had now been again raised; and he found, from a number of observations, some of which he obtained from other parties, and some of which he made himself, in the course of voyages he had occasion to make across the Irish Channel, that the skin resistance of an iron-built ship, moving at the rate of 15 feet per second, was 25 ounces per square foot of surface of plate, and he compared that result with some large experiments which he had had an opportunity of making in the case of a new cast-iron, but somewhat rusty, pipe laid in Liverpool, which was 44 inches diameter and 22 miles long, and he found that within an ounce per square foot the friction in both cases was the same. He compared it also with a similar new cast-iron pipe 3 miles in length and 13 inches in diameter, which supplied the town of Whitehaven with water, and with the Versailles 18-inch (French) pipe recorded by M. Couplet, and he found in all these cases a very close agreement with the resistances observed in the case of the ships. He would

give the data on which these conclusions were founded. In arriving at these facts he had taken a number of voyages in those vessels, and had ascertained the power that was exerted, the speed at which the ship ran, and the area of surface resistance which the vessel presented to the water. He had stated on previous occasions, and was still of the opinion, that the midship resistance was of no important value in the estimation of speed, when the vessel was of sharp build and going at a high velocity. There were considerable differences of friction, and smooth surfaces, so long as they could be kept smooth, would not offer half the resistance which a rough surface would present; and therefore between the worst case and the best, that of a very rough skinned ship, and of a very smooth skinned ship, there were many intermediate grades of resistance. The resistance of a ship loaded with barnacles or weeds would be much greater than 25 ounces to the foot, when moving at the rate of 15 feet per second, and therefore all those observations which were made with regard to what might be the coefficient in one case, and what might be the coefficient in another, were really of no value unless all the circumstances were distinctly given. With regard to iron ships, their surfaces were never in that smooth state for three months together.

There seemed to be some misapprehension with regard to what he had stated on a previous occasion.[1] He had then only devised a formula which represented, as he supposed, the different elements of resistance of steam ships, and a surplus of 25 per cent. for losses, and then he had said, after going into a discussion on the subject:—"Suppose it were wished to predetermine the speed of a vessel of nearly the magnitude and power of the 'Atrato,' and laid down on the following data, &c." These data were not the data of the 'Atrato,' although they were tolerably approximate. Nevertheless, they were indeed the data, as far as was known at the time, of a well-built, fast ship, of about the same tonnage as the 'Atrato.' He had said, according to that formula, the speed of the supposed ship would come out at $15\frac{2}{3}$ miles an hour. The 'Atrato' happened to be mentioned in the Paper which was read, and Mr. Hawksley had then said, "the 'Atrato' was stated by the Author of the Paper to have attained in fresh water a velocity of 16 statute miles per hour on the measured mile." He had only given that as a fact to show how closely, as he conceived, the results given by the formula approximated to the actual result stated with regard to the 'Atrato.' That result was obtained on the supposition that a ship of the supposed size, sailing in open sea, would, under ordinary circumstances, experience a resistance of

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xvi., page 357.

25 ounces per square foot; but if it had even been considerably less, the difference of speed would have been comparatively insignificant; because, supposing the estimate of the friction was reduced from 25 ounces to 16 ounces, then, with the same power, the speed would be increased only in the proportion of the cube root of 25 to the cube root of 16. He particularly wished to draw attention to the fact, that after a ship had been some time at sea, especially in a warm latitude, the condition of the surface was never the same as when on her trial trips, or the condition on which, he apprehended, the Author had based his assumption. Therefore Mr. Hawksley intended to support as a fact, till it was disproved by actual experiment, that an iron vessel had usually a surface resistance of about 25 ounces per square foot of wetted surface, when moving at the speed mentioned. He was, indeed, perfectly satisfied, that it would not be safe for the constructor of a sea-going vessel to calculate upon a lower resistance. The resistance of the midship section was of little importance in estimating the speed of fast vessels; but, of course, it had more effect on power than on speed. He saw no reason to alter the opinions he had expressed on a former occasion, when after giving the more elaborate formula, which included the midship resistance, he had made the following remark[1]:—

"It is worthy of observation, that, as respects sharp vessels, the speed may be approximately determined, without any direct reference to the midship section, by the very simple formula $V = 27\left(\frac{H}{s}\right)^{\frac{1}{3}}$; and as ($s$) frequently approaches the rectangle of the breadth (b) and the length (l), this becomes (approximately) $V = 27\left(\frac{H}{bl}\right)^{\frac{1}{3}}$, and therefore roughly $H = \frac{V^3\, bl}{20{,}000}$."

in which s = area in square feet of the wetted surface.
V = velocity in statute miles per hour.
H = indicated H.P.
b = breadth of vessel in feet.
l = length of vessel in feet.

That very simple formula $V = 27\left(\frac{H}{bl}\right)^{\frac{1}{3}}$ would be sufficient to express very approximately the velocity of any sharp-built iron steamship. He did not mean to say when the vessel was quite smooth and clean and well painted up, or if it were copper bottomed; but in the case of an ordinary iron steam-ship, in the ordinary good

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xvi., p. 358.

condition in which such vessels as the 'Persia' were usually kept, it was certainly within 10 per cent.; and, as he believed, generally within 5 per cent. of the actual speed attained in regular work.

To prevent any misapprehension in regard to the coefficient of 25 ounces to the foot, as applicable to an ordinarily corroded surface of iron, he wished to point out, that if the surface of a vessel were coated with paint and made smooth, then so long as the paint lasted there would be less surface friction; and with copper, also, as long as it lasted in a clean state there would be a still less surface friction. His previous remarks and assumptions had reference to a roughened and oxidized surface of iron, in the state in which it usually existed on the bottom of a vessel.

Mr. BIDDER agreed, to a considerable extent, with the conclusions arrived at by the Author, but in other respects, his views were more in accordance with the objections advanced against certain portions of the Paper. Before entering upon the discussion of the points at issue, he would protest against the employment of the term 'line of least resistance.' Such lines must necessarily vary with the class and purpose of the vessel, whether intended for the carriage of cargo, for making long voyages, or for short and rapid passages.

With regard to the question of surface resistance, it had been urged that the estimated value of 25 ounces at a speed of 15 feet per second was not the resistance due to a vessel in perfect condition, but it was admitted that it was the resistance to be practically calculated upon for a vessel on her passage; therefore he considered that the whole question raised by the Author on this point was conceded. In the course of the discussion it had been asserted, that the resistance due to midship displacement was so small, that it might be omitted from the calculation; and on the other hand it had been maintained, that this displacement exceeded the sine of the square; upon the latter hypothesis had been founded a theory which was so distinct from all the notions of ordinary hydraulics that he was compelled to dissent from it: he meant the theory with regard to the 'wave line.' He considered that, whether produced quickly or slowly, the resistance was due to the fact of there being a greater head of water at the fore part than at the remaining part of the bow. This was due simply to the circumstance, that however fine the cutwater of a vessel might be made, some interval of time must elapse before it accommodated itself to the ordinary condition of the surface of the water. What was called the wave-line had been introduced under the idea of communicating velocity to the water in a gradual manner. As regarded a sea way, the theory might be correct, but it was not so for smooth water, for as the velocity, inside the straight line and parallel to it, was then

due to the extreme angle and not to the average angle, the result would be in favour of the straight line; at sea there were other considerations which might be urged in favour of the wave-line. It would not be contended that the velocity given to the water was more than sufficient to clear a path for the vessel. In observations of vessels going through smooth water at their highest velocity, particles were observed skimming along by the side, but that could not occur, unless the condition was, as he had stated—that the velocity imparted was that which was required to enable the water to clear a path for the vessel. He would, however, take the instance of the 'Great Eastern:' her ordinary displacement at midship section was about 1,800 square feet; she had attained the velocity of 15 miles per hour, which was 22 feet per second, and represented a head of water of nearly 8 feet, which was about 500 lbs. per foot, or 900,000 lbs. over the whole superficial area of displacement. He did not think that the back pressure was as much as one-half, but the two pressures combined were nearly $1\frac{1}{2}$; that made a pressure of 1,350,000 lbs. upon the resistance due to the entrance of the vessels, and at 22 feet per second, it would require about 54,000 H.P. for itself alone, while the actual H.P. was not more than 10,000, from which was to be deducted about 3,000 H.P. for slip and friction, leaving for available H.P. 7,000. The skin resistance of that ship could not be much less than 50,000 feet; taking 25 ounces, one of the proposed coefficients, for 15 feet per second, it gave 54 ounces for 22 feet per second, which applied to 50,000 feet, gave 170,000 lbs. as the skin resistance; that sum divided by 150 gave 1,100, which multiplied by 6, gave 6,600 H.P. for skin resistance alone, and left only 400 H.P. for displacement. Such a result could not be reconciled, and necessitated the introduction of the sine square of the resistance of displacement and the adoption of a lower coefficient. On the other hand, for commercial resistance, this coefficient was too small: in fact, every vessel that left these ports for a voyage to the East Indies required a higher coefficient than 25 ounces. It was important to agree upon some datum for the discussion of this question. If that were done, it would be possible to measure the resistance of a vessel in perfect condition. A great step had been gained by the establishment of the fact, that the interior surface of a pipe did affect the flow of water. He, in common with others, had previously held a contrary opinion. As a matter of theory, there could be no doubt that, by the use of asphalte or other surface bearing a fine polish, an increase of flow might be obtained in pipes of small areas.

Mr. Ditchburn observed, through the Secretary, that the theory of resistance was very imperfect, and that conclusions drawn from it could not be depended upon. When a vessel was at rest, the mutual and equal pressures would neutralize each other; but

when a vessel was in motion, the water in her rear would follow and overtake her before those mutual pressures could be exerted. Hence it was evident that the pressure upon the after-part would be lessened, and the pressure upon the fore-part increased, and that the augmented resistance must be in proportion to the velocity of the motion of the vessel, and the form of her after-part. The action of the hull upon the fluid, as far as her progressive motion was concerned, ceased at the midship section; but there was an action of the fluid upon the hull produced by the gravitation of the water, causing particles to flow into the hollow formed by her continued advance. On the fore-body, however, of the ship, the effort of the water was increased in the ratio of the square of the velocity, so long as the velocity was maintained at a moderate degree; but beyond this degree, the resistances augmented at a still higher ratio, and even exceeded the cubes of the velocities, at some of the higher rates of speed, the effect of the fluid upon the after-body being diminished in the same proportion. Therefore, if a ship were going at the rate of 11 miles per hour, or 16 feet per second (which was about the velocity of a falling body at the earth's surface, and the utmost force of gravity upon water), that would be the velocity with which the fluid would fill up the hollow made by the ship; and as it was well known that a fluid could rush into a vacuum with a determinate rapidity only, it was important to discover what form of solid would give, while advancing at any assignable speed, the greatest facility to the divided fluid to reunite at the after-body. About forty-five years ago, he had conducted a series of experiments on the resistance of fluids for Sir R. Seppings, then Surveyor of the Navy, with the object of ascertaining the ratio which the resistance bore to the extent of surface under various given forms and angles. The models were of fir-wood, smoothly planed and painted. The experiments were made in a trough of water, about 4 feet square by 60 feet long; at an early stage of the trials it was observed that when perfectly dry models were used, the result was that the resistance offered by the water was much less than when water-soaked models were experimented upon, and to this fact was partly due the falling-off in speed of wood-built steamers. A wooden ship of 500 tons had been known to sink, from soakage, six inches in three years. There were twenty models, the bow ends varying from an angle of 186° to an angle of 12°. The result of these experiments was neither satisfactory, nor in accordance with the theory of mathematicians. According to theory, the resistance of a fluid decreased by the obliquity of its action, in the proportion of the square of the angle of incidence. Although these experiments were imperfect from the confined water-space and the small size of the models, yet it was apparent that the resistance to full bows was less, and to sharp bows and curved

surface, greater than that predicated by theory. This discrepancy might perhaps be attributed to the compound nature of the resistance of water to bodies dividing and passing through it; part of this resistance was due to the action of the water against itself, and consequently other elements of calculation required to be adopted besides the form and angle of the bow. He was not acquainted with any reliable law for ascertaining the precise difference of the resistance of water to plane and to curved surfaces, and to surfaces at different degrees of obliquity. The experiments he had referred to also strengthened his views as to the importance of the form of the after-part of vessels. They had also proved that resistance was increased more by the addition of length than of depth. He would mention that for the purpose of reducing what was called the 'plus pressure,' in other words, the water forced up by the stem and bows of a full-built vessel, he had introduced a slight hollow close to the stem. This modification of form had been applied to river steamers, and had had the effect of reducing the resistance and drawing down the head of water; and thus removing the chief cause of the unsightly and destructive bow wave.

Mr. E. A. Cowper could not agree with those who maintained that the shape or form of a vessel had very little to do with the total amount of resistance. Notwithstanding the numerous models which had been adopted by shipbuilders, he believed that as yet they had not arrived at the most perfect form for any given speed. It was possible that modifications of the curve, called the 'conoid,' which was very similar to that of a wave, might be found useful in forming the lines of a vessel. The most convenient way of drawing a 'conoid' was to fix a pencil on a rod, and fix a pin in the rod at the end, letting this pin run along a straight edge, whilst the side of the rod was kept in contact with another fixed pin at a distance from the straight edge. A variety of curves could be drawn by varying the distances, and by having a rod bent at an angle where the pin was fixed in it. Some of the curves would look like waves about to break, their crests being curved over very much, or the curve could be arranged to form a loop, one part crossing the other, as though the wave had actually broken. Fig. 1 (page 362), represented a 'conoid' drawn with a rod bent at an angle of 60°; Fig. 2, that at an angle of 40°; Fig. 3, that at angle of 20°; Fig. 4, that at an angle of 10°; and Fig. 5, that with a straight rod. It was worthy of consideration whether the forward motion of a particle of water due to the passing of the wave was not equal to the forward motion of the pencil.

He had made an experiment some time since, with a view of ascertaining what curve a water-line should be, to exert an equal pressure against the water throughout every square inch of surface

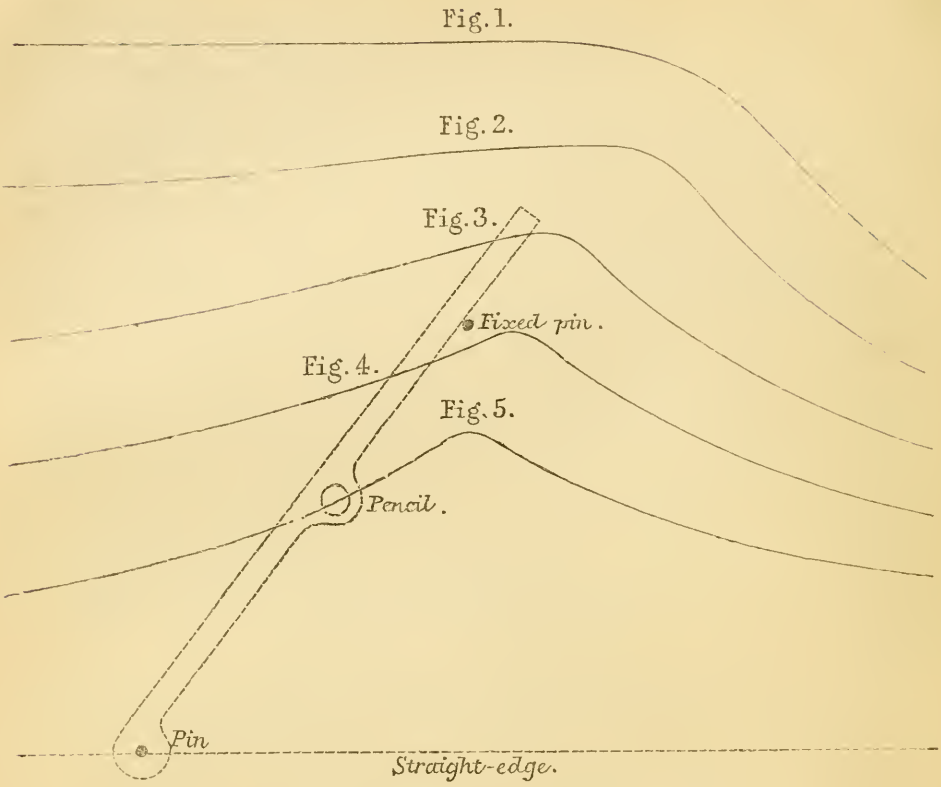


Fig. 1.
Fig. 2.
Fig. 3.
Fixed pin.
Fig. 4.
Fig. 5.
Pencil.
Pin
Straight-edge.

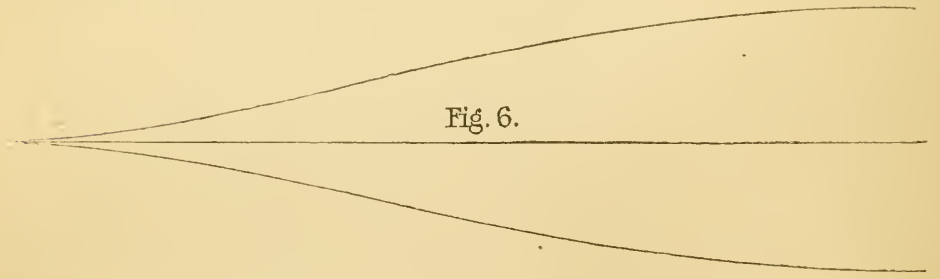


Fig. 6.

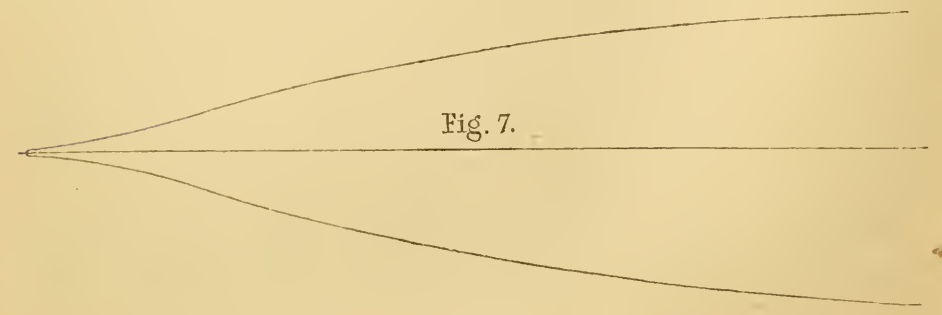


Fig. 7.

in its length; and in order to try this, for the fore-body of a ship, he made a rough wooden model which was so formed that the inside could be filled with water, the sides being quite flexible and only fastened to the flat wooden bottom, to the stem and stern posts, and to a bulkhead amidships; thus he had a rough boat with flexible sides, carrying an entire water cargo. This was towed through the water, in order to see what form the sides would take. When in motion the sides assumed a hollow and rounded curve, which varied in form according to the speed. If towed fast, the sides made a long hollow bow, with a gradual fulness towards the midship portion of the model (Fig. 6); whilst if towed slowly, they would take a smaller hollow curve at the bow, with a great fulness all the rest of the way to the midships. (Fig. 7.) This was to him a practical proof of the Author's proposition, that the resistance at the point of the wedge was greater than at any other part of the incline. It was evident that, with the water inside, the pressure must be equal throughout the length, and that the inside pressure increased in the depth exactly as the outside water increased in pressure. His experiments had been confined to the fore portion of the model, and although he did not assert that such a process gave the best form for a ship's fore-body, he considered it was a way of getting an answer from the water itself, as to what it would do under conditions of equal pressure.

There was one other point to which he would direct attention. It was important to find out, in what path the water passed round or under the bows of a ship, and came up or round under the stern of a ship. It had been stated that the water divided horizontally to allow the fore-body to pass, and rose up vertically to fill up the vacuity left by the after-body; but he believed that no one could tell in what path the water really did move round a ship, and he proposed to ascertain it by putting a number of small tin or copper weathercocks outside the ship, having their spindles passing through the sides at right angles, and having index fingers on the ends of the spindles inside, so that whilst the ship was running at any given speed, a note could be taken of the direction in which each finger and weathercock stood; then on going into dry dock, they could all be set exactly, and the path of the water could be traced on the outside of the ship. It was probable that different speeds would give different curves; but at all events, by such a device better opportunities would arise of making the true paths of the water into good lines. He had long been persuaded, that many more well-directed practical experiments, on which positive conclusions might be based, were necessary for the perfection of the art of ship-building.

Mr. W. Gravatt said that without entering into any mathematical calculations, he would briefly illustrate his views upon the

subject of the best form for a vessel's bows or line of least resistance. If two thin laths were bound together at both ends for a finite part of their length, so that a portion at each end was in absolute contact, then, if the remaining portion were spread open by the insertion of a strut somewhat nearer the bow than the middle; the figure resulting therefrom, would approximately represent the form of least resistance, taking into consideration the sides of the figure only. The curve could not be arrived at by considering the total resistance as that of the sum of the resistances of any number of inclined surfaces, since, as was evident, the resistance due to each portion was materially affected by the whole action of the portions which had preceded it.

Mr. Rickman drew attention to a model of the sailing-yacht 'America.' He explained that it was composed of a series of sections in the plane of the surface of the water, and the novel feature was, that these were sections of the vessel, taken not when in the upright position of rest, but when heeling over at full speed; consequently it would show how far the water-line of the lee side of the vessel presented a wedge of a fuller form, and that of the weather side of a finer form, than when she was, as usually draughted, upright and at rest. The superiority of the line of counter-flexure, commonly called the wave-line, and its claim to be considered the line of least resistance, had been questioned, and the preference assigned to the straight line. He had produced the model of the 'America,' which in 1851 had been distinguished by her swift sailing 'on a wind,' to show that she possessed a lee bow water-line of a very hollow though regular counter-flexure.

Mr. F. J. Bramwell said there appeared to be a want of concord in the opinions which had been expressed on this subject. With regard to the observations made by the Author of the Paper, as to the resistance of plane surfaces drawn through the water at right angles to themselves being only equal to once the height of the column due to the speed, instead of twice the column, as the theory required, he thought the following illustration might possibly clear up any doubt on that point:—If a jet of water of a given size issued against a large plane, the force developed by the jet upon the plane would be double that which was due to produce the motion; but if the jet were indefinitely large, a force equal to the head which produced the motion was all that was obtained. With this exception, his opinions were generally in accordance with those expressed in the Paper.

There could be no doubt as to the fact, that inclined planes had a resistance greater at the apex than at any other point; therefore if that circumstance were not borne in mind, an erroneous impression might be arrived at as to the operation of the inclination

of a bow. An opinion had been expressed, that it was almost impossible that the law of resistance should be directly as the square of the sine of the angle. But it appeared to him, that the law of resistance was in that direction, and under these circumstances he should have been glad if some experiments in support of that view had been adduced. He believed that if there were a flat surface in water, together with other surfaces of certain wedge forms, and that if those various surfaces and the water were quiescent, and then the power necessary to give them short but rapid motion against the quiescent water were ascertained, it would be found that in truth the resistance was directly in the proportion as the square of the sine of the angle. But if there were a flat surface in moving water, or the flat surface were moving through the water, he believed there was then a natural bow formed by the water itself. That was to say, the water did not strike the whole flat surface, as it would do had both the water and the surface been quiescent, until the rapid experiment referred to by him was made; but the water was gradually set in motion by the water-bow in front of the flat surface, and therefore the true effect of a flat surface for purposes of comparison with wedge bodies could not be obtained unless during very short trials, and in this way there arose an apparent discrepancy between the relation of the resistance to a flat surface and the relation of the resistance to a bow at an angle. It had been argued, by Mr. Scott Russell, that a nearer approximation to the truth of the rate of diminished resistance would be to calculate the increase of the area of escape, and to take the resistance as being diminished in proportion to the square of that increase. He thought that a formula based on such an assumption would be found almost as wrong as the other, and he would test this opinion by the following cases: suppose a perfectly flat disc, and that the area of escape was 180°, and next suppose a bow with infinitely fine lines, the area of escape being then 360°; as the area of escape was only doubled, the resistance should still be a fourth part of that required to propel a flat disc through the water. He thought that could not be, and that it was clear the resistance would have diminished in a far higher rate. In the consideration of this question no notice had been taken of the circumstance, that increasing the fineness of the wedge not only increased the area of escape, but diminished the amount of the water which had to escape. Mr. Bramwell concurred in the view, that the water removed by the action of the bow of the ship should be so displaced that at the termination of the action of the bow no momentum remained. Mr. Scott Russell proposed to accomplish this by adopting for the bow-lines double, or S curves, of such form as to accord, the one with a gradually accelerated, the other with a gradually retarded motion. This was

the problem mechanics had to solve when it was desired to obtain a reciprocating motion, and it was accomplished by setting out the cams which were to produce this reciprocating motion on the same double-curve principle. Mr. Bramwell did not say that the circumstances of the fluid water were absolutely the same as those of the solid material with which mechanics had to deal; but he thought there was sufficient analogy between the two problems, to enable any mechanical engineer to understand and appreciate the form of bow which had been recommended. He could not agree in the theory of the resistance diminishing in the ratio of the square of what had been called by Mr. Scott Russell the area of escape; but the Institution had to thank Mr. Russell for calling attention to two things. One was, pointing out the reason for the great power put forth by the rudder, over and above the apparent effect it should have, which undoubtedly showed why the balanced or "Throttled valve rudder" did not succeed; and the other was, for stating why in screw ships with large openings in the dead wood astern, the power of the rudder was diminished. Those two points he regarded as amongst the most important which had been elicited by the discussion.

With respect to the vexed question of surface resistance, it appeared to him that further experimental inquiry was wanted. No doubt it was difficult to believe, that the friction outside of any surface was different from that inside a pipe; because if it held good in a pipe of a given size it must hold good in a pipe of an infinite size. Nevertheless it was clear if the proper friction of an ordinary surface of iron inside a pipe was 25 ounces per foot at the rate of 15 feet per second, it could not, judging by the case of the 'Leinster,' be the proper friction of the outside of a ship in ordinary condition. No doubt there was difficulty in ascertaining the real value of the midship section resistance, as reduced by the effect of the form of the bow and the run; and until these were known it was difficult to find out the value of the skin resistance, which with that of the midship section made up the total resistance, which total resistance was ascertainable as being a percentage of the total indicated H.P. But although it was difficult to ascertain what really was the amount of resistance due to the surface out of the total resistance, it was quite clear the surface resistance could not equal the whole, still less could it equal the whole indicated H.P. But it would be seen that if the resistance inside a pipe were to be taken as the measure of the surface resistance of the ship, that of the 'Leinster' would considerably exceed the whole indicated H.P., as she was stated to make 30 feet per second, which was double the pace, and therefore gave four times the resistance of the 15 feet per second for which the 25 ounces were taken. The result of that upon 15,000 feet of skin would

be to consume 5,100 effective H.P. in driving the vessel, whereas the total H.P. was only 3,420. Thus it was clear that whatever the skin resistance might be, it could not be that which would be found inside a pipe. That being so, the question arose how the satisfactory data Mr. Hawksley had obtained, as to the friction of water through pipes, could be reconciled with the diminished resistance which it was clear must have existed in the case of the 'Leinster,' except upon the supposition that there was a difference between external and internal resistance? Might not the difference be due to the fact of the water being displaced by the bow, so that it was not in a state to give the full friction on the skin? Another matter bearing out that suggestion was, that in the table which had been exhibited, figures were given, for which Beaufoy and Mr. Hawksley were quoted as the authorities. Mr. Hawksley gave 1·56 for the surface of an iron ship; Beaufoy gave 0·763 for planed painted fir; while the Author gave 0·71 for a coppered ship; so that if a new iron ship and a coppered ship were taken for comparison, there was, according to these figures in round numbers, a skin resistance of only one half in a coppered as compared with an iron ship. He thought common sense taught, that the difference in speed between a new iron ship and the exactly same form of ship coppered was nothing like that due to the relative resistances of 2 and 1. If Mr. Hawskley's measure of friction for iron plates were correct, as well as that given by the Author for copper, every owner would have coppered ships, as they would get through the water at the same speed with half the power required for iron ships. As regarded the apparent slight differences between the friction of a rough and a polished surface moving through the water, he might mention that some years ago Griffiths' screw was applied to the 'Fairy' screw yacht. Indicator diagrams were taken at every mile, and the power carefully computed. Having obtained a very good result from the first screw, which was made of cast iron and put to work as it came from the sand, Mr. Bramwell had a similar screw made of gun-metal, and having had it well polished he looked for improved results. He found, however, there was no appreciable difference in the speed, nor any reduction in the indicated H.P., nor in the disturbance of the water.

He had only one other point to touch upon—that was the allusion in the Paper, confirmed by Mr. Scott Russell, as to the whole of the work being done by the early part of the screw-blade. In the Griffiths' screw of the 'Fairy,' the width of the point of the blade was 6½ inches, which replaced a screw of a width of 33 inches at that part. It was true the lower part of the Griffiths' blade was widened out, but the surface as a whole was nevertheless much diminished; notwithstanding that, the boat went a great deal better with the Griffiths' screw, showing that as far as screws went,

unless they were of an increasing pitch, the real work was done by the leading edge of the blade.

Professor W. J. Macquorn Rankine observed, through the Secretary, that he had successfully applied to steam-vessels a method of estimating their probable speed with a given I.H.P., or conversely, namely, their probable I.H.P. at a given speed. That method was based upon the work performed by the production of frictional eddies in the layer of water adjoining the skin of the vessel, and by its means he had correctly predicted the speed of the 'Great Eastern' at various amounts of I.H.P. From the results of his own experiments, and from the experiments of others, he could corroborate the opinion advanced in the Paper, that the frictional resistance depended much upon the nature and condition of the surface; and he had found that the coefficient of friction for clean and smooth iron ships agreed with the constant part of a coefficient deduced by Professor Wiesbach of Frieburg. That formula was deduced from experiments upon the flow of water in clean and smooth iron pipes; viz., 1 lb. per square foot for a speed of 10 knots. For copper sheathing and very smooth pitch, the amount due to resistance was decidedly less, but owing to the scarcity of exact experimental data, he could not state precisely in what proportion. Upon two points his method differed from that of the Author, and from another recommended during the course of the discussion; the first point was, that when the lines of a ship were truly proportioned, and when the length of her fore-body and after-body, but especially the after-body, bore certain relations to the length of the waves travelling naturally with the greatest speed of the vessel, he considered that there was no sensible resistance, except that caused by frictional eddies. The second point of difference was, that instead of simply multiplying the immersed surface of a ship by a quantity bearing a certain proportion to the square of her speed he took into account, by an approximate process, the various velocities of the particles, and the different resisting effect of a given extent of the vessel's surface according to its position. That process consisted in computing a quantity called the 'augmented surface of the vessel,' which was greater than her real surface: being the product of her length on the water line, her mean immersed girth, and a multiplier depending on her figure, called the coefficient of augmentation. In ordinary cases, that coefficient ranged from one and a small fraction, up to 2, according to the vessel's lines; in some cases, of extremely full form, it might be as much as 5.

The cube of the probable speed in knots was to be found by multiplying the indicated H.P. by a certain factor, and dividing by the 'augmented surface.' The value of the factor was subject to variations depending upon the state of the vessel's surface, the slip

of the propeller, and the efficiency of the engines; but when all those parts were in good order, 20,000 was a safe average value for iron ships. He was of opinion that as yet there was no exact method of calculating the resistance of a vessel, the length and form of which were unsuited to her speed. Deficient length of the after-body had been found in practice to be especially fatal to economy of power. Greater latitude might be allowed as to the length of the fore-body. As an example of his method, he gave an abstract of the probable speed of H.M.S. 'Warrior,' based on a computation of the exact measurements from her plans:—

H. M. S. 'Warrior.'

Displacement	8,997 tons.
Length on water line	380 feet.
× Mean immersed girth	76·3 „
× Coefficient of augmentation	1·275
Augmented surface	36,967 square feet.
Indicated horse power on trial	5,471
× Multiplier for clean iron ships	20,000
Divide by augmented surface	36,967)109,420,000 product.
Cube of probable speed	2,959
Probable speed by calculation	14·356 knots.
Actual speed on trial	14·354 „
Difference	·002

Mr. Phipps, in reply, said, as the correctness of the law, that the resistance was as the square of the velocity, had been impugned, he would wish to make some remarks in support of that doctrine before he offered any further observations upon the general question. The objections seemed mainly to be founded upon a series of comparative experiments made with H. M. S. 'Rattler,' a screw ship, and with the 'Alecto,' a vessel of similar lines but propelled by paddle-wheels. In the case of the 'Rattler,' the pressure of the screw shaft against the end of the vessel had been measured by the dynamometer, but he could not consider that the measures thus recorded were a true representation of the vessel's resistance, because he thought in screw vessels the pressure against the shaft was always greater than the real resistance of the ship. Referring to a drawing of the screw and stern of the 'Rattler,' Mr. Phipps pointed out the effect produced by the 'slip' of the screw in abstracting water from the stern, and thereby increasing the minus resistance. The quantity of water thus removed would, he said, probably bear a direct proportion to the 'slip,' and hence he concluded generally, that in order to give the true resistance of a vessel, it was necessary to deduct from

the thrust on the screw shaft a certain amount of force bearing a proportion to the 'slip' of the screw. When the 'Rattler' made a speed of 4 knots per hour, the slip was nearly three times greater than with a speed of $8\frac{1}{4}$ knots.

The pressure of the screw shaft at $8\frac{1}{4}$ knots was . . 6,213 lbs.
" " at 4 knots . . 4,780 lbs.

If from the 6,213 lbs. were deducted 1,200 lbs., being as the slip $\times$ 1, there would remain 5,013 lbs., for the true resistance of the vessel at $8\frac{1}{4}$ knots, and if from 4,780 lbs. were deducted 3,600 lbs., being as the slip = 1,200 lbs. into 3, there would remain 1,180 lbs. for the resistance at 4 knots, the two amounts of 1,180 lbs. and 5,013 lbs. being nearly in the proportion of 4^2 to 8.25^2. It was quite possible that the above figures might be only an approximation to the true resistances of the vessel, but he thought that they were sufficient to explain the general results of his reasoning. Mr. Phipps agreed with some remarks which had been made upon the excess of pressure upon the rudders of vessels, over and above that recognized by the ordinary theory; and whilst on the subject of steering vessels, he would direct attention to the difficulties attending the steering of large and long ships, and of turning them round rapidly on a short radius. He had computed the requisite force at the rudder of a ship 300 feet long and drawing 25 feet, in order to bring her round in five minutes, and he had found it would amount to at least 20 tons. When it was considered, that in order to save one minute out of the five minutes, the pressure against the rudder must be increased as 4^2 to 5^2, or as 16 to 25, or to more than 31 tons, the difficulty of all such attempts would be understood, though, it must be remembered, that in screw vessels, the impact upon the rudder, of the water set in motion by the screw, was a source of greatly-increased steering power. He would next notice that method of computing resistance which might be described, in general terms, as being based upon the displacement of water caused by vessels of similar type, their resistances being, as the squares of the cube root of their displacement. The objection to this method was, that when the type varied it was necessary to introduce into the computation some particular coefficient appropriate to each class of vessel. He thought that the method he had proposed was more general in its application. With regard to the accuracy, or otherwise, of Colonel Beaufoy's work on the resistances of solid bodies passing through water, the experiments referred to in that work had been carefully made, and, in his opinion, were trustworthy, especially those at from 5 knots per hour to 8 knots per hour, in which of course the friction was of less moment than at higher velocities, though in all the experiments, this friction had been duly ascertained and deducted. The experiments upon plus and minus

resistance, and the resistances of inclined planes, were also very instructive. It was true, that in the latter case no general law had been arrived at; but with respect to the resistance of any particular body, Colonel Beaufoy had shown that it was very nearly as the squares of the velocities, and it must be remembered, that where he had failed to deduce a general law for the resistance of inclined prows, no other Author had succeeded. In fact, it was quite impossible to approximate to clearness of ideas upon this point, until due value was given to the effect of impact upon the leading portion of the plane, as Mr. Phipps had endeavoured to illustrate in the Paper. It had been shown, in the course of the discussion, that if there was considerably more pressure at one end of a plane than at the other, it became impossible to lay down a general law, unless the planes were always of exactly the same length. This truth, once understood, there was no longer any difficulty in accounting for the large excess over the ordinary theory, in the case of very acute angled prows, or planes. Objections had also been made to the experiments of Beaufoy, because the bodies were entirely submerged; but it might be said, in favour of that method, that it avoided the great difficulty of valuing the effect of the wave raised at the bows, when the body was floating upon the surface of the water.

As to the effect of roughness, in diminishing the flow of water through pipes and open water-courses, it had now been admitted, that the resistance within a pipe was really affected by the roughness of its surface; and it therefore followed, that the fact stated, of the resistance within a pipe through which water flowed at a velocity of 15 feet per second being equal to 25 ounces per square foot of surface, could only be applicable under some given condition of the surface of the pipe. He had found, from an investigation of the experiments of M. Darcy, that this condition corresponded with a roughness a little greater than that of cast iron. But while the above admission had been made, it had still been contended, that the resistance within a pipe was a proper measure for that of a ship, when the average velocity of the water in the one was equal to the velocity of the other through still water, and that the true frictional resistance due to a velocity of 15 feet per second was 25 ounces per square foot, either for pipes, or for the surfaces of iron ships, on the ground that this formula was intended, not for the surfaces of new iron ships, but to be applied to mercantile vessels in their usual working condition. By referring to a previous discussion, when this formula was first given, it would, however, be seen, that after applying the formula to a supposititious vessel of nearly the power and magnitude of the 'Atrato,' a speed of $15\frac{2}{3}$ miles per hour was brought out; and then, it was added, "The 'Atrato' was stated by the Author of the Paper to have attained in fresh water

a velocity of 16 statute miles per hour over the measured mile."[1] Comparing, therefore, as had been done, the result of that calculation with the 'Atrato' when tried over the measured mile, the question naturally arose, what was probably the condition of the 'Atrato's' hull on such a trial over the measured mile? To which, as it appeared to him, the answer must be, that the hull was new and clean; and it was in this sense that he had always understood the matter. Next, as a matter of fact, he had found, from a reference to the plans of the vessel, that the amount of wetted surface of the 'Atrato' differed considerably from the vessel assumed as nearly similar; the amount of wetted surface in the 'Atrato' on her trial trip exceeded by 3,112 square feet that of the supposititious vessel. The indicated horse power of the 'Atrato' was 3,046 H.P., to which that of the supposititious vessel was nearly equal, namely, 3,000 H.P. The actual speed attained by the 'Atrato' on her trial trip, with the above power, was 13·77 knots, or 23·27 feet per second. Deducting 25 per cent. for observed slip of the feathering paddles = 761·5, and $\frac{1}{16}$th of the remainder for friction, working air-pumps, &c. = 228·4, there was left to propel the ship, a net power of 2,056 H.P. Now, according to the formula in question, a vessel of the dimensions of the 'Atrato' would have required, to attain the above speed, a net power of 2,806 H.P., which was probably sufficient to show that the coefficient of 25 ounces per square foot, at a velocity of 15 feet per second, was considerably too high.

As to the frictional resistance on the internal surfaces of pipes and open water-courses, as compared with that on the exterior of floating bodies, it had been argued that, when these two kinds of surfaces were equally smooth, the resistances were equal. His opinion, that the resistance on the internal surface was the greater, was founded upon the hypothesis of a greater velocity of flow of water in the latter, when, in general phraseology, the speeds were said to be the same. He had not in any degree founded his arguments upon the notion of circularity. Indeed no one acquainted with the usual method of calculating the resistance within pipes could for a moment suppose, that the difference of form in a circular pipe, or in a rectangular water-course, could cause any difference of resistance. All the rules were based upon the relation which the weight or volume of water in any given length of the pipe, or open water-course, bore to the wetted surface in the same length, the quotient, found by dividing the volume by the wetted surface, being the quantity usually denominated the 'hydraulic mean depth.' In a circular pipe, this hydraulic mean depth was always $\frac{1}{4}$th of the diameter, so that in a pipe of 4 feet diameter, the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xvi. p. 357.

hydraulic mean depth was 1 foot, being the same depth as that in an open rectangular water-course, of such great width as to neutralize the effect of the sides. If, therefore, a pipe 4 feet in diameter were laid at the same inclination as an open water-course of infinite width, and 1 foot in depth, the water would flow at the same average velocity in both. In explanation of his views of there being a greater resistance in the interior of a pipe or water-course than upon an external surface, he repeated that his arguments had nothing whatever to do with the form of the pipe through which the water flowed. But they were based upon the idea of a greater velocity obtaining against the frictional surface of the former, when the velocities of the fluid through the pipe, and of the exterior surface through still water were nominally the same. This might be shown generally, by stating that when a fluid passed along an inclined open water-course, the velocity of its motion was that of the average of all the different filaments, those at the surface moving more rapidly and those at the bottom more slowly. Therefore the relation of the bottom and nominal velocities of the fluid was the same as that of the average and bottom filaments. But when a vessel passed through still water, the case was different; for then the relation between the velocity of the vessel through the water in immediate contact with it and its nominal velocity, was as the velocity of a surface filament in a water-course compared with the bottom velocity of the water-course, when its velocity was the same as the nominal velocity of the vessel.

With respect to prows of various shapes, he was compelled to differ from the opinion, that a prow formed of perfectly straight planes would cause the least possible resistance in its passage through the water. The following calculation would illustrate his views on this subject. (Plate I., Fig. 7.) Resistances, taking the square end A K as unity :—

$$\begin{aligned} \text{A K} &= 1{\cdot}00 \\ \text{A D H} &= 0{\cdot}044 \\ \text{A H or L H} &= 0{\cdot}027 \\ \text{H I L} &= 0{\cdot}041 \end{aligned}$$

The usual method of calculating the resistances was by taking the ratio of the slant length A H^2 to the base A K^2, or by dividing the curved figure A B D E H into a polygon, taking each portion separately, as H F^2 to G F^2, &c., and then taking the sum of all the parts. According to that method, his own calculations bore out the suggested superiority of straight prows, for in the Table of Resistances, the resistance of the straight plane A H was to that of the curved surface A D H, as 0·027 to 0·044. But the above method was obviousl defective, for when applied to the straight

plane A H, no cognizance had been taken of the increased head resistance pointed out in the Paper, while, with respect to the curved surfaces A D H, each portion H F, F D, D B, and B A, had been dealt with as a separate plane, acting upon the surrounding fluid. Beaufoy's experiments invariably showed a smaller resistance for curved surfaces than for straight ones, when standing upon equal bases; the reason of this, there could be little doubt, arose from the circumstance, that each portion of a curved surface, excepting the entering angle, had only to act upon a fluid already in motion, and consequently suffered a less resistance than if it had been detached, as assumed in the ordinary calculation. Then, with respect to lines of contrary curvature, there was another circumstance which tended much to a diminished resistance. When the vessel advanced, a particle of water pushed outwards laterally by the sharp end of the prow would have its motion continually accelerated in the same direction until overtaken by the point of contrary curvature; its motion would be then retarded during the advance of the convex portion of the curve, and when reached by the fullest part of the vessel, it would be at rest. If this were so, the source of the advantage over the straight plane was evident; for although in the curved form the outward velocity was greater, at the point of contrary curvature, than it was on the straight plane which corresponded with the point of fullest convexity, namely, its base, yet all the work in the former, between the point of contrary curvature and the fullest part of that curve, was done without the application of additional force; whilst with the straight plane, the power must be exerted all the way from the point to the base of the triangle of which it was a part. It had been stated that the reason why a plane drawn square to itself through water did not realize the theoretical resistance of twice the altitude of column due to the speed, was that as a stationary plane, placed in such a way as to receive the full impact of a jet of water, did not realise the above theoretical resistance unless the area of the plane was considerably greater than that of the jet, so there was no reason to expect that a plane drawn square to itself through water would experience the full effect of a column of double the altitude; but Mr. Phipps did not think the analogy of the two cases complete. Newton and Young had attributed the diminished resistance to the action of a supposititious prow, formed of the fluid itself travelling in advance of the square plane; but, after mature deliberation Mr. Phipps had deemed the propagation of pressure in advance of the plane a more tenable theory, because under such propagated pressure all the fluid which required to be removed in a given time would be acted upon gradually, and pass away laterally, at a smaller mean velocity than that of the moving plane. In conclusion, he observed, that while admitting that the recorded perform-

ances of many of the ships referred to in the Paper upon High Speed Steam Navigation[1] did not agree with the principles laid down in his Paper, he was disposed to attribute that discrepancy to the fact of the vessels quoted being screw-vessels. He believed that, under certain circumstances, the screw caused great increase of resistance, and therefore in all experiments on resistance, he thought it better to exclude screw ships, because of their liability to be acted upon by unknown influences. His reason for the selection of the 'Leinster' as an example was, that all the particulars relating to that vessel were accurately known, including the slip of the paddle-wheels, the engine-power, and all other minor conditions.

March 22, 1864.

JOHN ROBINSON M'CLEAN, President,
in the Chair.

The discussion upon the Paper No. 1,105, "On the Resistance to Bodies passing through Water," was continued throughout the Meeting, to the exclusion of any other subject.

In pursuance of the notice on the card of the Meetings, it was proposed, and resolved unanimously,—

"That in order to insure a fuller attendance of Members than could be obtained on Easter Tuesday, the Meeting be adjourned until Tuesday evening, the 5th of April."

April 5 and 12, 1864.

JOHN ROBINSON M'CLEAN, President,
in the Chair.

The following Candidates were balloted for and duly elected on April 5th:—Robert Bruce Bell, John M'Connochie, Charles Markham, Daniel Miller, George Brice Pennell, Charles Staveley Rooke, and James Cobby Street, as Members; John George Knight, Frank M'Clean, Samuel Garlick Martin, and Charles Harcourt White, as Associates.

The discussion upon the Paper No. 1,105, "On the Resistance to Bodies passing through Water," was continued throughout both evenings, to the exclusion of any other subject.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xvi., p. 327.

April 19, 1864.

JOHN FOWLER, Vice-President,
in the Chair.

No. 1,116.—"Description of the Santiago and Valparaiso Railway, Chile, South America; with Remarks upon Resistances from Curves on Railways, and upon Coal-burning Locomotives."[1]
By WILLIAM LLOYD, M. Inst. C.E.

THE original proposition for connecting the capital of the republic of Chile with its chief port was made by an American citizen, Mr. Wheelwright, in the year 1850; and the success of the Copiapo line, which had been shortly before opened, appears to have encouraged the Government to take prompt measures to promote the undertaking; for in November of the same year, a decree of the executive was issued, commissioning its projector to proceed to make the necessary plans and estimates. After the expiration of rather more than a year from the date of this decree, Mr. A. Campbell, an American Engineer, whose services had been secured by Mr. Wheelwright, laid before the Government the plans, papers, and estimates of a line, extending from Valparaiso to Santiago, the estimated cost of which was stated at about seven millions of dollars. Upon the data thus procured, a company of Chilian capitalists was subsequently formed, under the auspices of the Government, and an Act of Congress was obtained, which received the President's signature in July, 1852, authorizing the prosecution of the works. In October of the same year, the works were formally inaugurated; but a dispute arising between Mr. Campbell and the Direction, that gentleman resigned his post; and the services of a staff of Engineers was secured from England, under the direction of Mr. C. Maughan, who, however, died a few months after his arrival in Chile. The Author was then appointed, and arrived in Chile in May, 1854. He found that, although a large sum had been expended, little real progress had been made towards the accomplishment of the scheme; and discovered that a much better route, in part, could be adopted than the line that had been selected. The Board of Directors, therefore, upon his recommendation, consented, in the month of July of the same year, to a complete reorganization of the system of management, as well as to the adoption, at a pecuniary sacrifice of upwards of £60,000, of an entirely new route.

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[1] The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

At this time, the construction of such works was imperfectly understood. The execution of the Copiapo Railway, from the extreme simplicity of its character, had been of little service in forming experienced workmen; the use of labour-saving appliances was almost unknown; wheelbarrows had only been introduced a few years; heavy weights were dragged along the ground with ropes and chains, by the united force of frequently forty or fifty men; rails and wagons in this part of Chile were now seen for the first time; pile-driving was unheard of; and stone-dressing, except in the softer descriptions of porphyrys, was considered impracticable. The work was carried on by gangs of twenty labourers, each gang having an overseer. These men received about 1*s.* 6*d.* per day, and, in addition, were supplied by the Company with rations. The overseers, often more ignorant than the labourers they directed, were allowed to keep shops upon the works, and, being possessed of unlimited authority, readily secured to themselves no inconsiderable share of the earnings of the workpeople, who were treated as serfs. For the refractory, each station was provided with stocks; these were generally well tenanted, and the lash was not spared, even for the most trivial offences. Under these circumstances, it seemed essential to place the workmen upon a more independent footing, both as regarded their means of labour, and those with whom they were compelled to deal. The provision of cranes, pile-engines, improved wagons, barrows, and other implements, with the requisite instruction in their use, became the Author's first care; and the establishment of the contract system, as soon as the prejudices against any alteration had been overcome, in a short time conspicuously displayed, not only the ability and intelligence of the native labourers, but the absurdity and barbarity of the coercive measures formerly considered indispensable.

When these preliminary arrangements were effected, the works progressed with considerable rapidity, and in September, 1855, the first 8 miles of the line were opened for traffic. In December, 1856, a further distance of 20 miles, as far as the town of Limache, was completed; and in May, 1857, the passenger traffic was commenced to Quillota, 7 miles beyond, a portion of the latter distance being of a provisional character, on account of the incomplete condition of a tunnel, subsequently finished through the San Pedro Hill.

From Valparaiso to Quillota, a total distance of 34 miles, the line was carried out by the original Company of Chilian capitalists, the Government taking about two-fifths of the shares; but upon its completion thus far, great difficulty was experienced in procuring the requisite capital to carry it on to Santiago, 80 miles beyond Quillota. Consequently the Government, on the application of the Shareholders, agreed, with the sanction of the

Congress, to buy up the stock hitherto held by private persons, to raise in Europe the additional capital required to complete the whole line, and to execute the remainder of the work on account of the State. This agreement was at once carried into effect, the private stock was purchased at par, and a loan of seven millions of dollars having been procured through Messrs. Baring Brothers, of London, the Government at once decreed the prosecution of the works. After the necessary interval had elapsed for the completion of the surveys, the first sod of the extension beyond Quillota was turned in September, 1859; the first 7 miles of the new line were opened in February, 1861; an additional 16 miles, as far as the station of Llaillay, in September, 1862; and the whole line was opened to the public in September, 1863, by the Author, as Engineer in chief to the Government of Chile.

The execution of this work, by far the most difficult of its kind upon the west coast of America, has occupied, therefore, nearly eleven years: during this period much valuable time has been sacrificed, and there is no doubt, that even in that remote country, where the facilities for carrying on such works are few, the whole might readily have been accomplished in one-half the time, but for the delays and impediments, which appear inseparable from all works carried on under immediate Government control.

That part of the west coast of South America embraced by the Republic of Chile has features which offer the most formidable impediments to the formation of railways, especially to those intended to traverse the Republic from east to west. The country seldom, in any part, exceeds 100 miles in width, yet in this distance there is a difference of level equal to about 20,000 feet. It is, in fact, simply a vast mountain slope, its foot bathed by the Pacific Ocean, and its perpetual snow-covered summit lost in the clouds; its surface ribbed by minor ranges of mountains, and furrowed by deep ravines, along which flow rivers rapid as mountain torrents. It also is volcanic, and subject frequently to such convulsions and oscillations as render necessary the exercise of more than ordinary prudence on the part of the Engineer. Rain-storms of unusual violence prevail during the winter months, causing imposing and impetuous rivers to rise with extraordinary rapidity in valleys where in the summer no stream exists.

In the consideration of the development of railway communications in countries presenting physical features that can alone be surmounted by extreme measures, and which are subject constantly to terrestrial disturbances, and not abundantly supplied with pecuniary resources, it becomes absolutely necessary to study how far enterprises of that kind can be carried out consistently with security and economy. Here the principles which should ordinarily govern an Engineer's decision are to some extent reversed. The first cost

of construction is more important than the future cost of working, on account of the expensive character of such undertakings, and their great distance from the manufacturing centres; and because, in comparison with the present cost of conveyance in the country, an unusually high rate of fares upon the line would still be an enormous economy to the public. Again, high velocities for the traffic are not demanded; the means of conveying the minerals and grain with regularity and facility, during all seasons, from the interior to the ports of shipment, being the chief desideratum; and further, the Engineer must consent to a certain sacrifice of economy, in order to obtain the requisite stability to resist the forces which the works may suddenly be called upon to bear. These characteristics are referred to, not for the purpose of showing that the most suitable means have been adopted for meeting such contingencies, in the case under consideration, but to invite the attention of the Institution to a subject not met with in ordinary practice—the construction of railways through volcanic countries, such as those bordering the Pacific and elsewhere.

The city of Valparaiso, the western terminus of this railway, is situated upon a shallow bay, fronting the north. It contains about 70,000 inhabitants, and is not only the chief port of the Republic of Chile, but is, at the same time, the principal commercial centre of the west coast of South America. It is the head-quarters of the English and French navies, and it possesses, by means of the Pacific Steam Navigation Company's steamers, a fortnightly communication with England, by way of the Isthmus of Panamá and the West Indies. Santiago, the capital of the Republic, stands at an elevation of from 1800 feet to 1900 feet above the ocean, in a broad and fertile plain, at the foot of the main 'Cordillera de los Andes.' It contains about 200,000 inhabitants, and is a handsome and well-arranged city. The distance from Valparaiso to Santiago, in a direct line, does not exceed 70 miles; but the physical obstacles presented upon this line of country, between the two cities, rendered the formation of a railway communication by anything approaching a direct route totally out of the question, and therefore it was necessary to seek some less obstructed means of admission into the central valley of Chile, in which the capital is situated.

The coach road, which pursues a tolerably direct course between the two places, demonstrates this fact very clearly. This road ascends abruptly from Valparaiso to an elevation of 1,300 feet, the altitude of the coast range at this point. It thence descends to the plains beyond, and crossing several subordinate hills, passes through the small town of Casa Blanca, which is distant 25 miles from Valparaiso, and is 830 feet above the sea. Beyond this place the road traverses a second broad plain, and then passes in a zigzag direction over a second range of mountains, the summit

of which is about 1,950 feet above the sea. Descending thence into the valley of Curacavi, it traverses 18 miles of tolerably level ground, at a general height of about 1,000 feet above the sea, and then encounters the third and loftiest range of mountains, over which it crosses at a level of 2,595 feet above the sea, descending afterwards to 1,800 feet, the altitude of the Santiago plain. These mountain passes are in themselves striking engineering works, and well repay inspection; yet the route offers to the conveyance of passengers and goods between the two cities the most serious impediment; and, to any ordinary traveller, the attempt to form a railway between these places would naturally appear wholly impracticable. The conveyance of all merchandise, between the capital and its port, has been conducted hitherto by means of large two-wheeled carts, drawn by eight bullocks, conveying about 2 tons; and the time occupied in the transit varied, according to the condition of the road, from six days to forty-four days. The cost of transportation varied also, according to the season, from £1 13*s.* per ton in summer, to £3 17*s.* per ton in winter; the average being about £2 17*s.* per English ton, or 2*s.* 6*d.* the Spanish quintal of 100 English lbs.

It will thus be manifest, that the economy of time and expense, by means of railway conveyance, must be enormous, and the result has effectually silenced those who asserted that such communications were too advanced for new countries; the fact being, that the ruder and more primitive the existing means of transport, and the more troublesome and laborious the actual communications, the sooner are the advantages of the great modern invention felt, and the more powerful is the impulse which it invariably gives to development and civilization. In the case under notice, the opening of the line will reduce the cost of conveying goods to one-third; while the time occupied in their transport will be diminished to five or six hours; and passengers, who have hitherto been charged a minimum fare of 10 dollars, or £2 each, by coach, will now be able, in half the time, to make the journey at an expense of $2\frac{1}{2}$ dollars, or 10 shillings.

The route, selected with much ability by Mr. Campbell, undoubtedly presented the most advantageous features, and was, after ample consideration, and with many alterations, ultimately carried into execution. This route left Valparaiso at its north-east extremity, and followed the coast until the embouchure of the Quillota river was reached, at a distance of 11 miles to the north. Thence the course of the river was followed past the town of Quillota to the Tabon Valley, by which the line was enabled to pass through one of the least elevated summits of the coast ranges, and thus penetrate into the central valley, along which it ran southwards into Santiago.

The most important deviation from this route consisted in carrying the line through Quilpué and Limache, thus avoiding some exceedingly troublesome work along the coast; while opening up at the same time the more productive and populous valleys of the interior. The line, as executed, diverges to the east from the shore of the Pacific, at 3 miles' distance from Valparaiso, at a place called la Viña del Mar (the Vineyard of the Sea), whence, passing up a valley of this name for a distance of 5 miles, and then through a ravine called 'Paso Hondo' (the Deep Pass), it reaches the valley of Quilpué. Along this valley it runs for about 10 miles, when, attaining a summit of 510 feet above the sea, it crosses a line of hills of moderate elevation, and descends into the Limache Valley. From this point the only means of penetrating into the Quillota valley was by tunnelling through a second range of hills, a spur from the 'Campana,' or Bell of Quillota, one of the most elevated summits of the coast range.

On reaching the town of Quillota, the line, as originally proposed, has been more or less adhered to, in its general course to Santiago, but with several important modifications, by which considerable advantages have been secured, and some of the more serious difficulties removed. Nevertheless, the rugged and mountainous nature of the country to be traversed has necessitated the retention of several sharp curves and steep gradients. From the following Table it will be seen, that in the above respects, the Tabon incline offers as striking an example as either the Semmering, the Bhore Ghât, or the Alleghany inclines.

Name of Incline.	Opened.	Length of Incline.	Total Rise.	Average Rise.	Sharpest Curve Radius.	Summit over Sea.
		miles.	feet.		feet.	feet.
Alleghany Mountains .	1851	15	1,690	1 in 47	600	2,626
Semmering	1854	13¼	1,325	1 in 47	625	2,887
Bhore Ghât	1862	15¾	1,831	1 in 48	990	2,027
Tabon	1863	12	1,360	1 in 46½	604	2,640

It also attains, it is believed, an altitude above the sea greater than any line, with the exception of the Semmering, yet constructed for the use of locomotive power;[1] and, so far as the Author is aware, is the first line upon this coast of America constructed by a Member of the Institution.

[1] The Chañarcillo line is 4,400 feet above the sea, but that line was not originally constructed for the locomotive.—W.L.

General Description of the Line.

The railway, for the first 3 miles from the Valparaiso station, passes along the coast of the Pacific, crossing its various indentations, or cutting through the projections of the granite cliffs. This portion is level throughout, and is about 12 feet above high-water mark. The line, however, is a series of curves of small radius, there being five of 660 feet, one of 750 feet, one of 800 feet, one of 818 feet, four of 900 feet, and three of 1,000 feet. All the exposed parts of this portion of the line are defended against the violence of the winter gales by massive sea walls, constructed of heavy granite blocks, laid dry, at an angle of 2 to 1, and upon these rest a parapet of masonry. The sea walls are protected in front by a foreshore, 30 feet in width, of heavy loose stone, and although on several occasions severely tried, have hitherto resisted perfectly the shocks of the seas which occasionally roll in with extraordinary violence. At two points, where sea walls would have been difficult of construction, the line is carried upon timber bearings, through which the seas pass; one of these being 300 feet in length, upon a curve of 660 feet radius. Upon this coast portion there are nine cuttings from 40 feet to 60 feet in depth, and one tunnel, 420 feet in length (the first railway tunnel executed in South America), all through syenitic rock, upon which lie beds of recent marine shells. It is reported, that the whole of this part of the coast, during an earthquake in 1822, was permanently upheaved to the extent of several feet. The beds of shells are, however, of much more ancient date, being met with at an altitude of more than 1,000 feet above the sea; and the upheaval, if such occurred, must have been remarkably uniform, as there remains no evidence of such recent volcanic action.

At the third mile from Valparaiso, the line diverges from the coast, and, passing through a cutting of more than 60 feet in depth, proceeds along the valley of Viña del Mar for 5 miles. Upon this portion the curves are generally good, and the gradients never exceed 1 in 100; the works also are of minor importance, but walls were required, in places, as a protection against the floods of the Quillota river, which, although dry in summer, is frequently 800 feet wide and 10 feet deep in winter. The course of this river is crossed by a wrought-iron plate-girder bridge of six 50 feet spans, which was the first bridge upon this principle erected upon this coast, and the line leaves the Viña del Mar Valley, and follows upward the course of the Quilpué river. In the two succeeding miles serious difficulties were encountered, commencing with a rock-cutting, 90 feet in depth, followed by a long embankment, 30 feet in height, and a second cutting, 40 feet in depth; immediately after which, in the next half mile, are four viaducts, each

above 60 feet high, crossing the Quilpué river, which here flows with a tortuous course, down a deep ravine with precipitous sides, about 600 feet in height. Two of these viaducts have spans of 110 feet, a third has two spans of 90 feet each, and the fourth has six spans of 66 feet each, the aggregate length of the four viaducts being 1,350 feet. These works were at the time of their construction by far the largest of the kind yet erected upon the coast of the Pacific, and are now only exceeded by the Maquis Viaduct, yet to be described. All these viaducts are upon a gradient of 1 in 50, and upon one of them commences a curve of 600 feet radius.

Beyond the fourth viaduct the valley becomes more contracted, and involved a succession of cuttings from 30 feet to 40 feet in depth, through a quartoze rock containing gold, which is here obtained by washing; and at one place, a fifth viaduct over the same river was requisite, of two spans of 60 feet each and 25 feet in height.

A short distance beyond this bridge the gradient of 1 in 50 terminates, and the line now ascends the Quilpué Valley as far as the eighteenth mile from Valparaiso, with gradients in no case exceeding 1 in 90. Upon this part the curves are not less than 1,000 feet in radius, nor are the works of serious importance. But at the eighteenth mile the summit of Lebu is attained, and here there is a cutting, partly in rock, $\frac{3}{4}$ths of a mile in length, with a maximum depth of 40 feet. From this summit, which is 510 feet above the Pacific, the line descends for the next $2\frac{1}{2}$ miles at the rate of 1 in 65; but the curves are moderate and the works are light: this gradient is succeeded by others of 1 in 90, as far as the twenty-fourth mile, at the Limache River, and upon this latter portion the principal works are a cutting 40 feet deep, $\frac{1}{3}$rd of a mile in length, and a timber viaduct of ten 24-feet spans, 25 feet in height.

The crossing of the Limache River, which in winter is a formidable stream, is accomplished by three bridges, together 500 feet in length, one of which is of wrought iron, and the others are of timber. The level of this part of the line is 215 feet above the sea. From this point the line again ascends by a gradient of 1 in 90, nearly 3 miles in length, upon which is a curve $\frac{1}{2}$ a mile long with a radius of 1,000 feet; and at the twenty-seventh mile from Valparaiso the second summit of San Pedro is reached, the level of which is 384 feet above the sea.

At this point the line passes through a spur of the Andes, by a tunnel 1,600 feet in length, approached on each side by rock excavations, each $\frac{1}{3}$rd of a mile in length, and of the maximum depth of 60 feet. This tunnel, the chief one upon the line, passes for $\frac{2}{3}$rds of its length through granite and trap-rock, containing much water, the remaining third being through decomposed rock and clay. It was

considered necessary to arch it throughout, and the novelty of such constructions in that country, the nature of the material perforated, and various legal difficulties connected with it, delayed its completion for so long a period, that it was deemed advisable to form a provisional line over the summit, by which the traffic was opened to Quillota four years sooner than it otherwise would have been. This provisional line was worked by one of the ordinary passenger locomotives employed as a stationary engine, and by its means 250 passengers and 100 tons of goods were daily conveyed over the crest of the hill; up inclines of 1 in 13 and 1 in 15 on each side, and over an altitude of 150 feet above the starting point, without the slightest accident during the whole period above mentioned.

This tunnel presented another peculiarity in the successful stoppage of a slip which took place at one point. This slip was occasioned by the decay of the timbering under the wet decomposed rock during the suspension of the works. When the works were resumed, the material descended into the tunnel as fast as it could be removed, in spite of every attempt to restrain it, until the surface of the ground, 120 feet over the tunnel, began to sink. The settlement above looked very alarming; but as it was considerably larger in diameter, than the orifice could possibly be below, the following plan was adopted and almost immediately took effect. The surface of the ground was allowed to settle about 10 feet, and a large frame of timber was constructed fitting the aperture, the timbers crossing one another like lattice work, and being strongly bolted together. Upon this lattice frame, brushwood was laid thickly, and the excavation below was then proceeded with. The frame rapidly disappeared, the sides of the cavity above the tunnel falling in as it descended; a short time was allowed to elapse, when a second frame of similar construction was again inserted above, and this was likewise covered with brushwood. Almost immediately after the insertion of the second frame, the miners below began to gain upon the slip, and at length were enabled properly to insert the timbering. It was discovered in doing so, however, that the first frame had descended to the tunnel, and had perfectly plugged up the aperture. This may not have been the first occasion that this plan has been tried, but it is mentioned as a successful instance of the stoppage of a slip, which, probably, could not have been arrested by any other means.

Beyond the San Pedro Tunnel, which is upon a gradient of 1 in 90, and partly curved, the line a second time descends into the Valley of Quillota, by gradients of 1 in 90 and 1 in 253, as far as the San Pedro River, which is crossed at the thirtieth mile. On this descent there are some rather heavy earthworks; but after passing the river, the country becomes favourable, and a straight

line of 4 miles, ascending at the rate of 1 in 172, extends to Quillota, an agricultural town of about 10,000 inhabitants, situated on the bank of the Aconcagua River, at a distance of 34 miles from Valparaiso.

The railway passes through one of the streets of this town; and, after leaving it, ascends the Valley of the Aconcagua for 20 miles, upon the first seven of which no difficulty of any importance was encountered. At the forty-first mile from Valparaiso, however, the line approaches the river, the course of which it follows for the next 13 miles, skirting as closely as possible the bases of the abrupt hills which form its southern bank; and, at places, the line is forced into such close contiguity with the stream, that extensive walls of loose stone have been rendered necessary for protection. The Aconcagua is one of the principal rivers of Chile. It rises in the main Cordillera, and takes its name from an extinct volcano, which is believed to be the loftiest peak of the Andes, rising to an altitude of about 23,000 feet. It is not navigable in any part, and having, almost throughout, a fall of forty feet to the mile, its current is extremely rapid; and during rain-storms, and also in the summer season, when the snows are melting, the body of water flowing along it is very imposing, although at other times insignificant in volume.

With the exception of the protective walls, in the construction of which a large quantity of rock from the hill slopes in the vicinity was used, the remaining works have no claim to any particular notice; but in passing round some of the spurs of the hills, a few curves of 600 feet radius became indispensable; these all occur on moderate gradients, and the principal portion of this extent of line is straight, ascending at the same rate as the valley itself.

At the fifty-fourth mile from Valparaiso, the line diverges from the bank of the Aconcagua River, and ascends the Valley of Tabon, crossing the Vichiculen River, by a skew plate-iron bridge of three 50 feet spans, at an angle of 29°; upon the first 3 miles in this valley the line is straight and the gradient moderate, until the station of Llaillay is reached, at which point the Tabon Incline commences.

The Tabon Incline.

The entire length of this incline is 63,347 feet, or nearly 12 miles. Its altitude at the commencement is 1,280 feet, and its summit is 2,640 feet above the sea. It therefore rises 1,360 feet, or at the average rate throughout of 1 in $46\frac{1}{2}$. It commences with a gradient of 1 in 100, for 1,700 feet in length, which is, for the most part, upon a curve of 1,495 feet radius; the ascent for the next 1,800 feet is increased to 1 in 48, on which gradient there is a continuous curve of 1,719 feet radius. The incline now con-

tinues with a diminished ascent of 1 in 68 for a length of 2,800 feet; here occurs the first curve of the minimum radius of 604 feet, and at the termination of this gradient, and upon the same curve, the maximum acclivity of 1 in 44½ commences. This maximum gradient of 1 in 44½, or 120 feet per mile, extends over the succeeding 3½ miles, and upon it occur sixteen curves of 604 feet, one curve of 633 feet, and one of 702 feet radius; the aggregate length of the curves combined with this gradient amounting to more than 1½ mile.

It is upon this incline that the principal difficulties of construction were met with. The Valley of Tabon terminates in a gorge, with perpendicular cliffs on both sides; through this gorge flows a small mountain stream, the bed of which descends with such rapidity, that the line to attain the upper part of the gorge, has been so carried along the abrupt and rugged sides of the mountains, as gradually to arrive at the required altitude. The railway, therefore, runs along the face of the mountain about 300 feet above the valley, and the rocky cliffs, in places, beetle over at an altitude of nearly 1,000 feet.

The works on this portion of the line consist of two tunnels through porphyry, respectively 500 feet and 350 feet in length; several heavy retaining walls, one 40 feet in height; a number of embankments from 30 feet to 80 feet in depth, and a succession of deep rock excavations. At one point, the line, for one-half its width, is in a cutting 70 feet deep, while the remaining half is formed of embankment, the slope of which extends down the hill side to about 250 feet below the rails. It was of course indispensable that the seats of all such embankments should be 'benched.' In addition to the ordinary excavations, a large number of loose rocks upon the hill sides required removal, lest the movement of earthquakes should cause them to descend, as on more than one occasion during the progress of the works similar rocks had been observed to do. In the execution of this part of the line, about 3,000 men, chiefly miners, were employed for two years; and a large quantity of gunpowder was used—blasts of 10 cwt., or 20 cwt. of powder being frequently employed.

Succeeding the gradient of 1 in 44½ just described, is a gradient of 1 in 46 for ½ a mile, the greater part being upon curves of 604 feet radius, and upon this gradient and curve are some heavy rock cuttings, in addition to the Maquis Viaduct.

The Maquis Viaduct is the principal work of its kind yet erected upon this coast. Its altitude in the centre is 126 feet, and its total length is about 200 yards. It has one span of 148 feet, and four spans of 100 feet, the former being tubular, the others formed of plate-iron girders. The piers consist of cast-iron columns, braced with wrought iron, and resting upon masonry. The

arrangement of the columns is somewhat novel, and the upper part of the piers is formed of a boiler-plate entablature, which has a good appearance, and affords great stiffness to the piers. The whole of the ironwork for this viaduct was obtained in England, Messrs. Kennard supplying the piers, and the 'Canada Works' the tube and girders. The best evidence of the excellence of its manufacture, is that the whole was erected in three months. The total weight of iron in this structure is about 750 tons, and the total cost of the viaduct, erected, amounted to about £40,000, or £66 per lineal foot.

The line, after passing this viaduct, immediately enters another tunnel, 350 feet in length, and the gradient again ascends at the rate of 1 in 44½ for a distance of rather more than a mile; the curvature, however, is less abrupt, the radii of the sharpest curves being respectively 718 feet and 955 feet. The works upon this length are still heavy, consisting of deep side-long rock excavations and embankments, with three plate-iron bridges over the Tabon River. Beyond this portion, a gradient of 1 in 46 extends for 3,800 feet. About one-third of this part of the line is straight; the remainder consists of curves varying from 800 feet to 1 mile in radius.

The incline now ascends, at the rate of 1 in 45, for 2 miles, the greater part of which is straight, and then is continued for 1,800 feet by a gradient of 1 in 50, on which are two curves of 662 feet and 717 feet radius respectively; and from the extremity of this gradient to the summit of Montenegro, a distance of 3 miles, the ascent is uniformly at the rate of 1 in 45; the curvature upon the latter being more moderate, most of the curves exceeding 1,400 feet in radius, and none being of less radius than 819 feet.

Upon the latter 5 miles of the incline, the works, excepting the summit cutting, which is 1½ mile in length, and on an average 30 feet deep, are not of an arduous description; but the material is, more or less, the same throughout, a tough porphyry conglomerate, exceedingly troublesome to blast.

Out of the total length of 12 miles of the Tabon Incline, 6$\frac{1}{10}$ miles are curved, and upon all the curves of less than 1,000 feet radius, it has been deemed prudent to lay a guard rail on the inner side of the curve. The permanent way is formed of fish-jointed T rails 84 lbs. to the yard, fastened to sleepers of two kinds of native timber, a species of cedar called 'Alerce,' and a cypress. The distance from centre to centre of the sleepers is 3 feet, the rails being fastened to them by wrought-iron spikes, weighing half a pound each.

The descent towards Santiago from the summit is effected for the first 3½ miles, with an inclination of about 1 in 80, the curvature being favourable, and the works light; a short interval

occurring upon this distance of 1 in 300, for the establishment of the summit station. To this gradient succeeds one of 1 in 183, for 2 miles in length; upon this distance, and indeed as far as the seventy-eighth mile from Valparaiso, the alignment is altogether favourable.

At this point, however, commences the third principal difficulty—the passage through an exceedingly deep and tortuous ravine 4 miles in length called 'San Ramon.' Upon this portion, there are three iron bridges over the River Lampa, and a continued succession of heavy earthworks, and extensive river walls; the aggregate length of these bridges is 800 feet, one being 40 feet in height, the two others are not more than 20 feet high, but both are askew, with angles of 30°. Two of the excavations approach 100 feet in depth, both in syenitic rock, similar to that encountered near Valparaiso, and many of the other cuttings reach the depth of 50 feet. The gradients upon this portion are respectively 1 in 55, 1 in 60, 1 in 71, 1 in 75, and 1 in 100, and upon the maximum gradient of 1 in 55, there are reversed curves of 600 feet and of 700 feet radii, extending throughout its entire length, for about one mile.

Beyond the ravine of San Ramon, which terminates at the eighty-second mile from Valparaiso, the country becomes more open, and the line is enabled to pursue a more direct course. Nevertheless, in passing the village of Tiltil, and in approaching Polpaico, the rapid declivity of the valley necessitated the introduction, in one or two cases, of gradients of 1 in 67 and 1 in 72; the works at this part are exceedingly light, and the material consists chiefly of gravel.

At Lampa, where there is a station, the line again crosses the river of that name, by an iron bridge of eight spans of 50 feet each, and thence, as far as the ninety-third mile, there are no works of importance, except a bridge of two 66-feet spans over the Chacabuco River.

Just beyond the ninety-third mile from Valparaiso, the line leaves the valley of the Lampa, and traversing a low range of hills with a cutting about 30 feet deep in shale, descends for the extent of one mile at the rate of 1 in 52, into the valley of Santiago, near the Batuco Lake, which is crossed at the ninety-sixth mile. The lake is at this point nearly a mile in width after rains, but is of little depth; the line is carried across it by an embankment having its slopes protected against the wash of the water by loose stone. From the embankment to the one hundred and eighth mile, the line is throughout straight, and practically level; nor in the remaining six miles to Santiago was any particular difficulty encountered, except in passing two points at Renca, of basaltic rock, and in crossing the Mapocho River by a bridge at the entrance to the capital. The bridge consists of three spans of 100 feet each,

supported upon cast-iron cylinders 6 feet in diameter, let into the bed of the river to the depth of 23 feet, and afterwards filled with concrete. This system of foundations, employed in this case for the first time on the coast, has been universally admitted to be the best adapted, and most economical for bridging the rivers in Chile, on account of their rapid currents and frequent liability to floods.

The termination of the Santiago and Valparaiso Railway in the capital, is at an extensive station, serving also for the 'Southern Railway of Chile,' a line now in operation for 84 miles through the most fertile provinces of the country, and which it is proposed to extend ultimately as far as the frontier of Araucania.

This detailed description of the principal features of a Chilian railway, may, it is believed, be of interest, to those who are called upon to exercise their profession in countries such as that under notice; and the Author entertains more confidence in this respect, because descriptions of similar cases, recorded in the Minutes of the Proceedings of the Institution, have afforded him previously much valuable data. Nor can he forget, that it was chiefly through the advice and counsel of the late Robert Stephenson, and by the encouragement of other friends connected with the Institution, that he has been enabled to carry out successfully a laborious and difficult task.

Particular stress has been laid upon the combination of steep gradients with abrupt curves, because in countries like Chile, railway communications cannot be effected without them, and any practical data respecting them cannot fail to be of value. In the published account of the Bhore Ghât, the Semmering, and other principal inclines, this information is not given with sufficient distinctness, to afford accurate conclusions, as to the positive impediments offered to the traffic of those lines; therefore, appended to the Paper is a list,[1] containing the lengths of every curve and straight line upon the Tabon Incline, specifying the gradient upon each.

The subject of the resistances due to such combinations, is of the utmost importance, and will probably bear much more investigation than has hitherto been devoted to it. American Engineers, such as Latrobe, who have had great experience upon this point, appear to underrate the effect which curvature produces in retarding the passage of trains. English authorities differ materially in their views upon the matter, and a recent writer gives two formulæ for arriving at an estimation of this resistance, which are perfectly opposed to one another, so that reliable data seem yet to be wanting. A few imperfect experiments made by the Author, upon the Paso Hondo Incline of 1 in 50, with curves of 600 feet radius, and upon the level line nearer Valparaiso, with similar curves,

[1] This list may be consulted at the Institution.

although not presented as more than mere approximations to the truth, may at least afford matter for discussion.

The experiments were made with a dynamometer, constructed in Chile for the purpose, similar to a spring-balance in its form and arrangement; but of only sufficient power to enable the experiment to be made with one loaded wagon, an ordinary four-wheeled open goods wagon, having wheels 7 feet apart, and weighing when empty 8,200 lbs. For the purpose of this experiment it was loaded with pig-iron, until the gross weight amounted exactly to 10 tons. It was then drawn at a slow rate by a locomotive, so as to enable the observers to note the effect. The observations were taken upon a calm day.

RESISTANCES to RAILWAY TRAINS, in lbs. per Ton of Train.

On Straight Lines, Level, and Inclined.

If Curved or Straight.	Gradient.	Friction, Concussion, &c.	Gravity.	Resistance from Curvature.	Total of Resistances.	Observations.
		lbs.	lbs.	lbs.	lbs.	
Straight	Level	10	..	..	10	Satisfactory.
,,	1 in 500	10	2½	..	12½	Moderately good.
,,	1 in 875	10	5	..	15	
,,	1 in 250	10	5	..	15	Imperfect.
,,	1 in 200	10	10	..	20	Satisfactory.
,,	1 in 180	10	10	..	20	Fair.
,,	1 in 114	10	20	..	30	
,,	1 in 111	10	25	..	35	
,,	1 in 100	10	20	..	30	Satisfactory.
,,	1 in 50	10	40 to 45	..	50 to 55	
			On Level Lines and Curved.			
Radius. feet.						
660	Level	10	..	15	25	
880	,,	10	..	7½	17½	
900	,,	10	..	10	20	
1000	,,	10	..	10	20	
1300	,,	10	..	7½	17½	
1 mile	,,	10	..	2½	12½	
			On Inclines and Curves combined.			
Radius. feet.						
600	1 in 50	10	45	15	70	
1000	1 in 50	10	45	10	65	
1500	1 in 50	10	45	5	60	
600	1 in 100	10	20	15	45	
1000	1 in 100	10	20	10	40	
800	1 in 100	10	20	10	40	
1500	1 in 100	10	20	5	35	
3000	1 in 100	10	20	5	35	
2000	1 in 200	10	10	5	25	
5280	1 in 875	10	2½	2½	15	

It will be noticed that some of these results are slightly contradictory; but the approximations to the ever-varying indications of the dynamometer, as observed by two persons, are the closest that could be made. According to such experiments, it is apparent, that upon a straight line, with a gradient of 1 in 50, the resistances correspond with those afforded by the ordinary mode of calculation, viz., about 55 lbs. per ton of train; while upon the same gradient, combined with curves of 600 feet radius, the resistances were augmented to 70 lbs. per ton of train; showing that the additional resistance, due to the curvature, amounted to 15 lbs. per ton of train. By the formula of Latrobe, the resistance due to a curve of 600 feet radius, would amount only to about one-third of the above result, viz. 5·09 lbs. per ton of train; while Professor Rankine (in his "Civil Engineering," 1862, p. 648) approaches much closer to the results of these experiments, as his calculation would give 12·3 lbs per ton of load, which seems to be much nearer the truth.

These experiments would appear to show that, upon a curve of 1,000 feet radius, the resistance is double that upon a straight line, and that the resistance produced by a curve of 600 feet radius is equal to the gravity on an inclined plane of 1 in 150.

Approximately, the resistance due to curvature may be found by either of the two following rules:—Divide the number of lbs. in a ton by 0·224 of the radius of the curve; or, multiply the deflection angle of the curve by 1·75 to give the resistance in lbs. per ton of train due to curvature.

It should be remarked, however, that the gauge of the line on which these experiments were made, is 5 feet 6 inches, and that the proper super-elevation of the outer rail had been given to the curve.

The plant employed upon the Santiago and Valparaiso Railway is upon the European system, the engines and most of the other rolling stock having been obtained from England. The engines are at present of two classes, ordinary six-wheeled passenger and goods engines, four wheels being coupled; but special engines have been ordered for the Tabon Incline.

The dimensions of the engines now in use are as follows:—

	Passenger Engines.	Goods Engines.
Length of fire bars	3 ft. 6 ins.	3 ft. 6 ins.
Width of ditto	3 ft. 9 ins.	3 ft. 9 ins.
Surface of ditto	13·12 sq. ft.	13·12 sq. ft.
Number of tubes	161	193
Length of ditto	11 ft. 6 ins.	11 ft. 6 in.
Inside diameter of ditto	$1\frac{3}{4}$ ins.	$1\frac{3}{4}$ ins.
Fire-surface of ditto	848 sq. ft.	1,016 sq. ft.

	Passenger Engines.	Goods Engines.
Heating surface of fire-box	74 sq. ft.	78 sq. ft.
Total fire-surface	922	1,094 sq. ft.
Inside diameter of boiler	4 ft. 2 ins.	4 ft. 2 ins.
Quantity of water in ditto	730 gals.	730 gals.
Pressure of steam in boiler	110 lbs.	120 lbs. per sq. in.
Steam cut off in cylinder	17, 15, 13, 10½, 8¼, 6, 3, ins.	17, 15, 13, 10½, 8¼, 6, 3, ins.
Diameter of cylinder	15 ins.	16½ ins.
Length of ditto	26 ins.	28 ins.
Stroke of piston	22 ins.	24 ins.
Diameters of leading and driving wheels	5 ft.	4 ft. 6 ins.
Ditto of trailing ditto	3 ft.	3 ft.
Gauge of rails	5 ft. 6 ins.	5 ft. 6 ins.
Centres of wheels, leading to driving	8 ft.	8 ft.
Ditto, driving to trailing	5 ft. 6 ins.	5 ft. 6 ins.
Extreme centres	13 ft. 6 ins.	13 ft. 6 ins.
Width of tires	5 ins.	5 ins.
Incline of tires	1 in 6	1 in 6
Weight on leading wheels	20,065 lbs.	24,000 lbs.
Ditto on driving ditto	24,000 lbs.	26,000 lbs.
Ditto on trailing ditto	9,016 lbs.	9,016 lbs.
Ditto, engine empty	53,081 lbs.	59,016 lbs.
Ditto, tender ditto	18,600 lbs.	18,600 lbs.
Water in tender	1,000 gals.	1,000 gals.
Fuel in tender	2,000 lbs.	2,000 lbs.

The fuel employed is exclusively native coal, from the mines of Lota, a port about 300 miles south of Valparaiso. The engines were originally intended to burn coke, but Mr. Mather, the Locomotive Superintendent of the line, at a trifling expense, not exceeding £5 each, has, by skilful adaptation, fitted them for using coal, and effected an economy in the cost and consumption of fuel of about 30 per cent. The alterations consisted in placing in the fire-box a firebrick bridge in front of the tube-plate, just below the level of the tubes; underneath this were introduced two hollow stays in the front of the fire-box, to admit air. A deflecting-plate was likewise added for the fire-door, which is made to ship, or unship at pleasure; and an annular steam-jet was introduced within the chimney, the exhaust-pipe being cut down, at the same time, to a level of 1 inch above the top row of tubes, leaving its diameter 5 inches. In addition to these alterations, the fire-bars were lowered 5 inches (leaving them 28 inches below the tubes), and were brought much closer together. The effect of the alterations has been most satisfactory. Formerly the fuel employed was one-quarter English coke, at 16 dollars per ton, and three-quarters Chile coal, at 9 dollars per ton; and the average consumption per mile, with light trains, was 9·41 lbs. coke, and 26·15 lbs. coal = 35·56 lbs. fuel per mile; and the expense per mile was 17 cents, or 8½*d*. The consumption at

present, of coal only, is 35·80 lbs. per mile for goods engines, and 22·86 lbs. per mile for passenger engines, or an average of 29·83 lbs. per mile of fuel; and the cost of coal in Valparaiso being taken at 9 dollars per Chile ton of 2,200 lbs., as before, the expense per mile run is, for passenger engines, 9 cents, or $4\frac{1}{2}d.$, and for goods engines, 14 cents, or $7d.$, the average being $11\frac{1}{2}$ cents per mile, or $5\frac{3}{4}d.$

This economy has no doubt, however, been materially assisted, by the application of a jet of water from the boiler upon the flanges of the leading wheels of the engines, which has enabled them to pass round the sharp curves of the line with great ease. The coning of the engine-wheels has also been increased, from 1 in 7 to 1 in 6, with great advantage, not only to the working of the engines, but to the permanent way.

The total number of miles run by the nine engines in use during the month of October, 1863, amounted to 22,164; the greatest number of miles run by any engine, is 3,445; and the whole of the engines have been in use from seven to eight years.

The duty that the engines of this line can perform will be best understood by the following notes of trains conveyed up the Paso Hondo, Tabon, and San Ramon Inclines:—

Observation 1st.—Train with $16\frac{1}{2}$-inch cylinder goods engine, up Paso Hondo Incline, gradient 1 in 50, with curves of 600 feet radii.

	lbs.	tons.
8 American platform cars, weighing	113,136	
400 rails, 21 feet long, 84 lbs. per yard	235,200	
Timber, &c.	17,520	
Weight of train . .	365,856 =	163·33
„ engine . .	89,616 =	40·00
Total weight .	455,472 =	203·33

Velocity of train, 10 miles per hour, or 880 feet per minute; the resistance, by experiment, for incline and curve being 70 lbs. per ton:—

$$\frac{70 \times 203{\cdot}33 \times 880}{33000} = 379 \text{ H.P.}$$

Tractive force exerted, $70 \times 203{\cdot}33 = 14233$ lbs., or rather more than one-fourth of the weight on the driving-wheels of the engine.

Observation 2nd.—Train with 15-inch cylinder passenger engine, up Tabon Incline, gradient 1 in 44, with curves of 600 feet radii.

	lbs.	
2 first-class passenger carriages occupied	39800	
3 second ,, ,, ,,	63960	
Goods van	20720	
Horse box	12900	
1 loaded wagon	22000	
1 empty ,,	8000	
Weight of train	167380	= 74·72 tons.
,, of engine	83681	= 37·35 ,,
Total weight	251061	= 112·07 ,,

Velocity of train, 10 miles per hour, or 880 feet per minute; resistance for maximum gradient and curve, 77·5 lbs. per ton;

$$\text{Then } \frac{77{\cdot}5 \times 112{\cdot}07 \times 880}{33000} = 231 \text{ H.P.}$$

and $77{\cdot}5 \times 112{\cdot}07 = 8685$ lbs. the tractive force exerted, which is about one-fifth of the weight upon the driving-wheels of the engine.

Observation 3rd.—Train with 15-inch cylinder passenger engine, up San Ramon Incline, maximum gradient, 1 in 55, with curves of 600 feet radii.

	lbs.	
4 first-class carriages	62800	
3 third ,, ,, ordinary	43800	
1 break van	14000	
1 third-class carriage, bogie trucks	25000	
Luggage	8400	
450 passengers	63600	
Weight of train	217600	= 97·14 tons.
,, of engine	83681	= 37·35 ,,
Total weight	301281	= 134·49 ,,

Velocity of train, 10 miles per hour, or 880 feet per minute; resistance for maximum gradient and curve, 67·4 lbs. per ton;

$$\text{Then } \frac{67{\cdot}4 \times 134{\cdot}49 \times 880}{33000} = 241 \text{ H.P.}$$

and $67{\cdot}4 \times 134{\cdot}49 = 9064$ lbs. the tractive power exerted, equal to rather more than a fifth of the weight upon the driving-wheels.

From these observations it appears to result, that the ordinary class of passenger engines, upon inclines of 1 in 44, with curves of 600 feet radii, can convey a gross weight of train equal to about double their own weight; that similar engines up inclines of 1 in 55 with curves of 600 feet radii, can convey rather more than two and a half times their own weight; and, finally, that one of the present goods engines of this line has taken up a gradient of 1 in 50, combined with curves of 600 feet radii, a gross weight of train equal to four times its own weight.

At first, in working the Tabon gradient, considerable inconvenience and loss were caused, by the burning of the break-blocks of the tender. A remedy was applied by allowing water to drip upon them, and being successful, the drivers were led to try the plan of wetting the rails in ascending the inclines, after the engine had passed, so as to ease the train round the curves. The effect proved so satisfactory, that all the tenders are now being fitted with a perforated pipe underneath on each side, so that the outer rail of the curves can be sprinkled with water, and the resistance be thus reduced.

The traffic of this railway, so recently opened, is of course yet undeveloped, but its prospects are encouraging; and although the expense of its construction has been heavy—the cost of the entire line having amounted to nearly $11\frac{1}{2}$ millions of dollars, or about £20,000 per mile, inclusive of rolling stock—yet there is a confident expectation that its results will be satisfactory to the country.

The present traffic returns are 23,192 passengers of all classes, and 5,000 tons of goods monthly. The receipts amount to 54,168 dollars, so that a return may be expected of about 3 per cent. or 4 per cent., after paying expenses. This amount of profit may be considered sufficient, as the object of the government is to afford the utmost facilities for the transport of goods in this part of the republic; and a moderate tariff has been established, so as to bring the benefit within the reach of all, and to distribute the advantages as much as possible. The passenger fares are, for first class, at the rate of $2\frac{1}{4}d.$ per mile, for second class, $1\frac{3}{4}d.$ per mile, and for third class, $1\frac{1}{8}d.$ per mile. For goods there are three classes, the highest being at the rate of $3d.$ per mile per ton, and the lowest at the rate of $2d.$ per mile per ton. Of course, it must be obvious that upon such a line, and in a country where fuel, stores, and skilled labour are so expensive, these rates would be completely unremunerative, but for the position the Government occupies in the undertaking.

The length, cost, plant, and consumption of fuel of the railways of Chile, are shown in the following table:—

Name of Line.	Length in Miles.	Cost of Construction, without Plant.	Plant.			Fuel and Consumption per Mile.
			Engines.	Carriages.	Wagons.	
		Dollars.				lbs. cents.
Santiago and Valparaiso	114·32	10,734,798	10	36	135	Coal 29·83 cost 11½
Southern	83·50	5,606,281	10	37	154	Wood 63·50 „ 13·61
Copiapò	74·15	2,960,183	14	11	166	Coke 47·19 / Wood 1·74 „ 43·19
Chañarcillo	26·00	1,000,000	2	18	81	Coke 67·73 „ 85·00
Coquimbo	40·25	1,040,000	5	6	102	Coal 31·00 „ 14·00
Totals . . .	338·22	21,341,262	41	108	638	

It will be noticed, that the Santiago Railway is worked more economically than the others. The difference in the expense upon the Chañarcillo line is due, in a great measure, to its exceptional features. It was originally constructed for a horse-tramway, and therefore has inclines of 1 in 33 for 14⅓ miles, and 1 in 24 for 9 miles, and it attains an altitude of 4,400 feet above the sea. It is now, however, worked by locomotives, constructed by the Messrs. Hawthorn.

Among the general characteristics of the country through which the Santiago and Valparaiso Railway passes, there is much that is attractive and interesting to the general observer. Gold, silver, copper, and plumbago are met with at various points, and the primary volcanic and basaltic rocks are especially well represented. Of the vegetation, the principal objects to be noted are cocoa-nut palms, cacti, the prickly pear, the wild fuchsia, myrtle, and verbena; also the wild potato, artichoke, mint, sage, and other well-known herbs. In natural history, there is an ample field for study; whales, pelicans, seals, and penguins are seen upon the coast; wild swans, geese, and flamingoes are met with at the Batuco Lake; and, among the rocks of Tabon, the noblest specimens of the condor, together with the diminutive humming-bird, may be seen; while eagles and vultures are common; and at times, but only during severe weather, the puma and guanaco (the latter a mixture of the llama and deer), have been observed upon the line.

The social contrasts presented by this railway, are equally interesting. The most primitive means of transport—the pack-horse, or mule, and the hide drawn along the ground by bullocks—are here side by side and in competition with the most recent forms of locomotion; the earliest and rudest form of plough is employed in the same field with the most modern thrashing-machine; while sun-dried bricks (the clay kneaded by the feet of bullocks), are manufactured in close vicinity to one of Clayton's machines worked by steam-power.

In conclusion, the Author will briefly call attention to the main results of the experience afforded by this work.

With reference to the means for resisting the effects of earthquakes, it is believed that by fish-jointing the permanent way, more security has been obtained. A few years since, a portion of the Copiapò line, where it passed over swampy ground, completely disappeared, and the rails were lost. The permanent way, in that instance, was spiked to transverse sleepers, and the joints rested in plate-iron chairs, and were readily disconnected.

In bridge constructions, lofty piers of masonry have been avoided, and ironwork substituted; brick arches, for the same reason, have been considered inferior to plate-iron girders, as being more liable to disturbance by sudden shocks. All abutments of bridges, or retaining walls, have been constructed with battering sides; extra thickness of work has been allowed, and bond courses of ashlar have been introduced at frequent intervals.

By the employment of native fuel, not only considerable economy has been effected, but the superiority of Chilian coal has been manifest over the English coal, as introduced into the country. Its qualities for the production of steam are beyond all doubt; but, though highly inflammable, it requires so large a supply of atmospheric air for its perfect combustion, that the fire-doors of the locomotives are never closed.

The application of the hot-water jet upon the leading wheels of the engines, has so facilitated their passage round curves, that, provided sufficient play be allowed to the trailing-wheels, not only is the resistance diminished, but the tires are preserved, and bogie trucks, with all their various inconveniences, seem to be unnecessary.

Again, the application of moisture to the rails from the tender, in passing round abrupt curves upon steep gradients, the rails for the engine remaining dry, reduces the resistance due to curvature in a sensible and important degree; and by the same means the break-blocks, in descending inclines, can be prevented from igniting.

An attempt to adapt screw piles as foundations for a bridge upon a quicksand, was unsatisfactory in its results; it having been found impossible to force the pile down to a sufficient depth, in consequence of the sand becoming jammed in the screw. Cast iron, or timber piles had therefore to be substituted.

Similar long and steep inclines to the Tabon, combined with curves of 600 feet radius, may be introduced without hesitation when necessity requires their adoption; even without any extraordinary and special locomotive arrangements being requisite, until the augmentation of the business of the line demands it.

These remarks are presented in the belief, that it is only from the comparison of practical results, with the experience of others,

that the true principles which should govern the Engineer in the formation of his plans can be ascertained; and also as a slight acknowledgment of the advantages derived by the Author, from the publication of similar information by the Institution.

The Paper is illustrated by a map of Central Chile, showing the Santiago Railway; by complete plans and sections of the entire line; by a plan and section, to a small scale, of the Tabon Incline; by drawings of the Marquis Viaduct; and by various photographic views; as well as by an Appendix comprising a Table of the straight and curved lines upon the Tabon Incline, with the gradients upon each.

[Mr. Paddison

Mr. Paddison observed, that the line was originally intended to go along Point Concon, and thence up the valley of Quillota. That route had been commenced before Mr. Maughan's arrival in Chile, at which time, considerable progress had been made in the cuttings. The whole of the coast consisted of decomposed syenite, and the hill-slope, facing the sea, was covered, to a thickness of 20 feet, with sand, which, in dry weather, the wind drove into the cuttings so rapidly, that it was impossible to keep them open; and, in wet weather, the cuttings were entirely filled by the land waters. Therefore it was already a question whether the coast line should not be abandoned. But Mr. Lloyd wished to have some practical information before coming to that decision. Shortly after his arrival a violent storm occurred, by which works to the value of £60,000 were rendered practically useless. Battens of 20 feet scantling were washed away into the sea, and cuttings 30 feet deep were filled up, and it then became a subject of serious consideration, not merely whether that route should be abandoned, but whether the line should be constructed at all.

Mr. Fowler, V.P., said, there were two points of importance which had not been alluded to. One was, whether, at the junction of reverse curves, a straight piece was inserted, and if so, of what length; the other was, as to the cost of working the line.

Mr. Paddison called attention to the section of a reverse curve of 600 feet radius, with a gradient of 1 in 50. In that instance, owing to the tortuous nature of the valley, it was impossible to insert any straight line. As a rule, a straight piece was inserted where practicable. He was not prepared with any information as to the cost of working. The price of earthwork varied from 1*s*., to 1*s*. 6*d*., and 2*s*. per cubic yard.

Mr. Edward Woods said, the Paper was a record of one of the most important works carried out in South America. He had been connected with the line from its first projection down to the present time, and had supervised the construction of the materials for its permanent way, iron bridges, and working plant. In its general features, it resembled in many respects the other lines that had been constructed in that country. As stated in the Paper, all the lines connected the coast with the lower part of the mountain range, therefore all had to encounter severe inclines, and required that extremely sharp curves should be used. On the Copiapò Extension line there were gradients for about twelve miles of 1 in 30, eight miles of 1 in 23, and two miles of 1 in 27; so that the whole twenty-eight miles consisted of steeper gradients than those on the Valparaiso line, whilst the curves were of smaller radius—the sharpest being of 500 feet. With respect to the Copiapò Extension Railway, owing to the

steepness of the gradients, it was proposed, in the first instance, to work with animal traction; consequently the rails laid down were lighter than if it had been intended to use locomotive power. But after the opening of the line, a severe drought rendered fodder scarce, and the expense was found to be so great, that though mules were used for twelve months, it was determined not to continue that mode of working, and it became necessary to design engines adapted to those steep gradients and sharp curves, having reference also to the lightness of the rails, which weighed only 42 lbs. to the yard. With respect to the construction of those engines, in the first instance it was a necessary condition, that the weight on any one of the wheels should not exceed 7 tons; for the rails were not strong enough to be subjected at any one point to a greater pressure. To obtain the necessary adhesion and evaporative power, the weight had to be subdivided, and be distributed upon three pairs of driving-wheels and a four-wheeled truck in front. The engines were accordingly constructed with that view; the three pairs of driving-wheels were 4 feet in diameter; the cylinders were 16 inches in diameter, with a length of stroke of 24 inches, and the front end rested on a 'bogie' truck, on four wheels. By that arrangement, these engines had been able to pass round the sharp curves with the greatest ease. In other respects, the construction was similar to that of engines in England. The boilers were of ample size, and the total weight of each engine did not exceed 30 tons in working condition, with a tender of about 20 tons (loaded). The loads averaged from 50 tons to 60 tons, exclusive of the engine and tender, on the gradient of 1 in 23. The length from the centre of the leading driving-wheels to that of the trailing-wheels was 10 feet 9 inches. The leading driving-wheels had no flanges, in order to facilitate the passage round the curves. Those engines, manufactured by Messrs. R. and W. Hawthorn of Newcastle, from the time of their being placed on the line till the present time (a period of three years) had worked without a day's interruption, and without accident. When first called upon to design the engines for the Santiago and Valparaiso Railway, he had some prejudice against the truck arrangement, and he decided upon the ordinary English construction, allowing considerable end-long play in the axle of the hind driving-wheels, so as to admit of its yielding to the curvature. The result was upon the whole satisfactory, but he had received complaints of the great wear and tear of the flanges and tires arising from the friction in passing round the sharp curves. It seemed, that recently, that difficulty had been in a great measure overcome by the application of jets of water to the wheels. He thought, that application was, in such cases, valuable, and one which might render bogies unnecessary where the curves

were not extreme; but he inclined to the opinion that the simple Bissell bogie construction was the best for these lines.

He had recently sent out for the Coquimbo line, a tank engine, connected with a two-wheeled bogie truck, and he had received a report stating, that nothing could be more satisfactory than the working of it. It rounded the sharpest curves with great ease, at a speed of 30 miles per hour, and ran as smoothly as a first-class carriage.

There was one observation in the Paper, with reference to the screw pile, which had attracted his attention. The screws were stated to have been provided for a bridge across the Viña del Mar river, and to have proved unsuccessful, the structure having been carried away by a flood. He did not think the same result could be predicated of the use of every kind of screw, which might be adapted for hard, or for soft ground, as circumstances required a different form and pitch. With regard to the cost of working lines in Chilé, the consumption of coke on the heavy gradients of the Copiapò line was about 70 lbs. per mile. Coal had not yet been employed, but it was hoped to introduce it with success and economy, by using the native coal, instead of importing from England, which could only be done at a great expense. The average working speed of the line was about 12 miles per hour.

One circumstance worthy of remark was the great rapidity with which the works of the Santiago and Valparaiso Railway were executed after the Government had undertaken them—a rapidity which, he believed, so far exceeded expectation, that the line was ready for opening five months before the stipulated time, and long before the rolling stock was prepared, so that the early traffic had to be carried on with such plant as was at hand. He might add, that in consideration of the rapid completion of the work, the contractor received the bonus offered by the Government.

Mr. Phipps inquired, what amount of super-elevation was given to the outer rails on curves of 500 feet or 600 feet radius, for a speed of 30 miles per hour? He considered that any experiments, confined to the pulling of a single wagon, were an insufficient test of friction; and that when a train was drawn slowly, over a curve of small radius, there might be a greater pressure against the inner rails than the outer ones.

Mr. Woods replied, that the average speed was not more than 15 miles or 16 miles per hour upon curves, when, he thought the super-elevation of the outer rails would be from 3 inches to 4 inches.

Mr. Paddison stated that, on the reverse curves of 600 feet radius, with an inclination of 1 in 50, the super-elevation was 5 inches.

Mr. Vignoles begged to add his testimony to the extreme amount of ingenuity, courage, and skill with which the works

had been carried out. There was no railway he knew of in any part of the world in which such great objects had been accomplished in so economical a manner. He had carefully perused the Paper (not knowing anything of the Author, or of the country except generally), and after inspecting the plans and the photographic views, he would say, he knew nothing equal to them. Although he might take exception to some of the details, he not only assented to the conclusions, but went further, and attributed a greater amount of resistance to the curves, and consequently of power to overcome that resistance, than had been set down in the tables.

Mr. GILES did not quite understand whether, on a gradient of 1 in 40, there was a curve of so small a radius as 600 feet. He would also ask whether in Chile, where, judging from the photographs, there was a great abundance of stone, the Engineer would not have found it more economical to substitute stone, instead of cast-iron, piers, for the viaducts, considering the long carriage and the necessarily expensive nature of iron work in that country?

Mr. VIGNOLES said, it was stated in the Paper, that iron-work was used for various reasons, and amongst others the sufficient one, he thought, of obviating, as much as possible, the effects of shocks of earthquakes. Speaking from his own experience, he found that in such countries, notwithstanding the abundance of stone, it was better and cheaper to make embankments in some cases, and to employ iron-work in others, although the iron required a considerable amount of cartage; because the lime and sand were not found with the stone; and, that being the geological character of Chilé, he thought the Author had exercised a sound judgment in using iron.

Mr. WOODS said the reasons given by Mr. Vignoles for preferring iron to stone were quite correct. The question of earthquakes was one that required the attention of Engineers carrying out works in volcanic countries, both as regarded ordinary buildings and railway constructions; and under any circumstances, the erection of large masses of masonry was objectionable. That was one reason no doubt why iron had been used Iron structures had a degree of elasticity which prevented their being injuriously affected by slight shocks of earthquakes. Another reason in favour of iron was the great cost of skilled labour in the country, in addition to which, there was the question of time; iron-work prepared in England and sent out, being erected so much more quickly than masonry. The curves prevailed over almost all portions of the line, including the long incline of 1 in 40, and that was the case also on other lines in Chilé. Sharper curves and steeper gradients were common, and he had previously mentioned one line on which the gradients were 1 in 23, 1 in 27, and 1 in

30, and he was reminded that, on the Semmering incline of 1 in 40, there were curves of 600 feet radius.

Mr. COLBURN could not agree with the statement, that the resistance was doubled on a curve of 1,000 feet radius, and that a resistance of 15 lbs. to the ton occurred on a curve of 700 feet radius. He thought any one who had had much practice upon railways, would be opposed to the belief, that the resistance was as great as was assumed in the Paper. He was once familiar with a piece of road on an American line, where the rise was 20 feet to the mile, with a level curve of 700 feet radius at the top. He had been up and down that line many hundreds of times, and he had repeatedly observed, that in ascending, the engine increased its speed on passing from the ascent on to the level curve. The driving-wheels might be making 180 revolutions per minute in ascending the 20 feet rise; but the speed increased to 190, 200, and even 210 revolutions on the curve; and as, in that case, the gravity due to the incline was less than $8\frac{1}{2}$ lbs. per ton, the resistance due to the curve could not have been more than 6 lbs. or 7 lbs. per ton. On a decline of about 27 feet to the mile, he had seen carriages run down through curves of 1,100 feet radius without coming to a stop in the curve, although the gradient was but little more than the angle of friction. About eight years ago he made a number of experiments for the superintendent of the New York and Erie Railway—a line of 450 miles in length—with a view to ascertain what a single engine would draw over every part of that line. The gradients and distances of each section were:—Eastern division 74 miles long, gradients of 1 in 88 both ways; Delaware division 104 miles long, gradients of 1 in 354 going west, except for 15 miles between Deposit and Susquehanna, where there were inclinations of 1 in 88 both ways; 'Gulf Summit,' near Susquehanna, being 1,360 feet above the sea; Susquehanna division 140 miles long, 1 in 528 both ways; and Western division, 128 miles long, 1 in 132 going east, and 1 in 105 going west, 'tip top' summit 1760 feet above the sea. A train was started at Dunkirk, on Lake Erie. The engine had outside cylinders, 17 inches in diameter, with a length of stroke of 24 inches, and four coupled 5-feet driving-wheels, with a weight of about 18 tons, or 40,500 lbs. on both pairs of driving-wheels. The train was started, with all the load that could be got, over the inclines on the Western division. When Hornellsville was reached a train was in waiting there, consisting of one hundred 8-wheeled loaded cars, each weighing upwards of 15 tons. The whole weight of the train, as far as Susquehanna, was 1,570 tons, with the engine, the train being more than half a mile in length. Some portions of that line were practically level, though at places there were gradients of 10 feet to the mile. On the level and straight portions and through

the curves of 900 and 1,100 feet radii the train, consisting of eighty wagons, was taken at a speed of from 10 miles to 12 miles per hour. At Susquehanna it was divided, and consisted of twenty-two wagons to Deposit, 15 miles east of Susquehanna. From Deposit to Delaware was 90 miles, over which the whole train was taken, and a great part of that distance was level, with a succession of curves of 956 feet radius. The train went through those without any difficulty, the load being 1,570 tons. Supposing the resistance had been 10 lbs. to the ton, there would have been a tractive power required of 15,700 lbs. He regretted, that at that time they had no indicator diagrams; but there was never more than 130 lbs. pressure in the boiler, and, taking that as the pressure on the piston, it would have given only a little more than 15,000 lbs. tractive power, so that there could never have been more than 10 lbs. pull per ton upon any part of that train. He believed the adhesion was $\frac{3}{8}$ths of the weight on the driving-wheels. If in the instance referred to, the adhesion was less than 15,000 lbs., it effectually disproved the assumption of double resistance on a curve of 1,000 feet radius. He was quite sure, the resistance on curves was nothing like 15 lbs. per ton, on a radius of 700 feet, and as to its being doubled on a radius of 1,000 feet, he was quite convinced it was nothing of the kind.

Mr. Bidder, Past President, said, it must be borne in mind, that the resistance on a curve was not the same at all velocities. The resistance of a curve was a function of the velocity; but he could not understand how a tractive power of 15,700 lbs. was got out of a weight of 18 tons on the driving-wheels. That was different from anything Engineers were acquainted with in England.

Mr. Colburn said, the proportion between the weight on the driving-wheels and the adhesion was, in this country, assumed at $\frac{1}{6}$th or $\frac{1}{7}$th. He found, from his own observations on the Great Eastern Railway, that it was $\frac{1}{4}$th, on the Brentwood incline. His statements as to the weight of the train referred to, might be entirely relied upon, as he knew exactly to what weight the cars were loaded. Sand was freely used on the rails when necessary. He thought, sometimes there were more than 130 lbs. of steam on the boiler, and even with that pressure, there was a difficulty in accounting for the resistance of the train. The resistance could not have exceeded 10 lbs. to the ton, at parts of the road where he should have expected it to be 15 lbs. He regretted that no further details of the experiments were published, beyond what were furnished in a report to the Directors of the New York and Erie Railway Company; but he promised a Paper giving the results of these trials to the Institution.

Mr. Bidder, Past President, said, the difficulty was as to the

adhesion, and if a Paper were brought before the Institution during the present session, he should like to have that question discussed, inasmuch as at present he was not prepared to admit an adhesion of less than 1 in 3. At the same time he should be happy to have his theory corrected by absolute facts. With sand there would be more adhesion, and the resistance of 10 lbs. per ton would then probably become 15 lbs. or 20 lbs. per ton.

April 26, 1864.

JOHN ROBINSON M'CLEAN, President,
in the Chair.

No. 1,113.—"On the Structure of Locomotive Engines for ascending Steep Inclines, with Sharp Curves on Railways."[1] By JAMES CROSS.

A LOCOMOTIVE engine for ascending steep inclines in combination with sharp curves, should not only possess great facility for moving freely round those curves, but combine safety and steadiness when travelling at high speeds on straight lines; so as to enable the engine, which has brought its load across the plain, to traverse a mountain ridge and continue its journey on the level ground beyond. The other desiderata are large boiler power, in order always to command a full head of steam; and ample accommodation for fuel and water, so distributed as to give increased adhesion to the driving wheels without unduly loading them; thus a separate tender (itself no small load on a heavy incline) can be dispensed with and greater available haulage power or duty can be obtained. The ordinary locomotives are primarily adapted for running on straight lines, and although these engines do go round curves, it is only by a continual antagonism between the leading and trailing wheels and their superincumbent weight. The wheels try to mount the outer rail, by the frictional adhesion of their flanges, and the weight presses the flanges to the rail, which acts as a grindstone; while the engine itself moves round by a succession of jerks, every one of which represents a blow, to the framing, more or less severe, according to the speed and the radius of the curve. The cost of repairing the framework, axle boxes, guide blocks, &c., on long engines traversing sharp curves, is therefore a heavy item in locomotive expenditure. Steep inclines are generally worked by tank engines, and, for the reasons already given, a powerful tank engine of ordinary structure, if it carries fuel and water for a long journey, is, from its short wheel base, a source of serious injury to the permanent way; while if this evil be avoided, the engine can only carry a supply for short distances, and in many cases at a great disadvantage.

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[1] The discussion upon this and the following Paper occupied portions of two evenings, but an abstract of the whole is given consecutively.

Again, the torsion on the axles of ordinary locomotives when traversing curves is very great; the only means by which the tires of the wheels can adapt themselves laterally being their conical shape. This is not in itself sufficient, even on curves of large radius; and on curves of small radius, and on the multitude of deviations from the straight line caused by irregularities in the rails, it is altogether useless; and hence the rapid destruction of tires and rails. This mischievous friction, again, reacts on the haulage power of the long engine, so that many of the old four-wheeled engines are nearly equal in haulage power, on sharp curves, to six-wheeled engines, wherein the haulage power is reduced to a minimum, when the curves are combined with steep gradients. For this reason, locomotives are occasionally unable to start again after stopping on ascending curves, the wheels being rail bound; and it would seem, that for a line on sharp curves, a four-wheeled coupled engine, properly balanced, is much more economical than a six-wheeled engine, and is, to all intents, as effective.

An attempt to meet the foregoing requirements, and, as far as possible, to obviate the disadvantages named, has been made by building a locomotive fitted with Adams's radial axle boxes and spring tires. This was built as a passenger engine, and is not therefore cited as a specimen of a powerful engine for steep gradients combined with sharp curves, but as a specimen of a long-based engine passing freely round curves which are impassable to the ordinary engines of 15-feet wheel base, and as illustrating the principle which is believed to be the best adapted, by its simplicity and efficiency, for working all lines with sharp curves, with or without steep gradients. It is thought, that the results of the actual working of this engine will be valuable, as any reasonable amount of power can be provided in future engines.

The following are some of the principal details: There are eight wheels; the leading and trailing wheels are each 3 feet 3 inches in diameter, and are fitted with radial axle-boxes; the driving-wheels are each 5 feet 1 inch in diameter, placed immediately in front of the firebox, and coupled to a similar pair immediately behind it. Krupp's tires are used on all the wheels, with springs between the tire and the periphery. The distance from the centre of the leading wheel to the centre of the driving wheel is 7 feet; from the centre of the driving wheel to the centre of the coupled wheels, 8 feet; and from the centre of the coupled wheels to the centre of the trailing wheels, 7 feet. The rigid wheel base measures 8 feet. The total wheel base is 22 feet. The total length of the framing is 31 feet $\frac{3}{4}$ inch. The weight on the leading wheels is 7 tons 15 cwt.; on the driving wheels, 11 tons

15 cwt.; on the coupled wheels, 11 tons 5 cwt.; and on the trailing wheels, 4 tons 10 cwt.; so that the total weight is 35 tons 5 cwt. when empty.

The cylinders, which are inside, are 15 inches in diameter, with a length of stroke of 20 inches. The fire-box is 4 feet $1\frac{3}{4}$ inch by 3 feet $3\frac{3}{8}$ inches inside. The boiler is 10 feet 5 inches long, and 3 feet $2\frac{3}{4}$ inches in diameter. The fire-grate is 5 feet by 3 feet $3\frac{3}{8}$ inches. There are 121 tubes, each 10 feet 11 inches long, $1\frac{7}{8}$ inch outside diameter, and $\frac{7}{8}$ of an inch apart. The heating surface in the tubes is 620 feet, in the fire-box 67 feet: total 687 feet. The pressure is 140 lbs. on the square inch. The tank, on the same framing as the engine, holds 950 gallons of water, and the bunker carries 25 cwt. of coal. The foot-plate is covered with a cab. There are no peculiarities in the fire-box, boiler, or motion, though, it may be remarked, that this class of engine gives great facilities for the use of the long boiler, and hence for economising the heat of a coal-burning fire-box.

The novelty of the engine is in the radial axle-boxes, which allow an engine on one rigid framing, carrying both boiler and tender, to pass round extremely sharp curves with an easy gliding motion, while the great length, controlling all irregularities, makes the engine very steady at high speeds. The construction in effect reduces the real wheel base of 22 feet to 8 feet when passing round curves, this being the distance between the coupled wheels.

The radial axle-boxes are only a little larger than ordinary engine axle-boxes; but, instead of being square to the framing, are struck with a radius which has its centre in the centre of the adjoining axle, giving, in this case, a radius of 7 feet, which the axle-box guide-blocks are curved to fit. The boxes are allowed to play laterally $4\frac{1}{2}$ inches on each side, and the spring-pins, instead of being fixed immediately on the top of the boxes, are each fitted with a small slide or roller, so as to allow the boxes to traverse freely. It will be at once seen, that the latter, though of a different shape, are still only axle-boxes weighing $3\frac{1}{2}$ cwt. each, and that the only additional parts added to the engine are the spring-pin rollers. This simplicity so completely answers the desired end, that it is claimed as one of the best features of the new engines. The action of the axle-boxes is as follows:—On entering a right-hand curve the flanges of the leading wheels draw the boxes to the right, the framing remaining as a tangent to the curve; and, as the axle-boxes are themselves curved, the result is to bring the axle on the right-hand side nearer to the driving wheel, and to push it on the left-hand side further from the driving wheel. The trailing axle, in its turn, takes a similar position, and the leading and trailing axles thus become radii of the curves they are tra-

versing, and keep their flanges always parallel to the rails; and the boxes, moving freely from right to left, adjust themselves to the multiplicity of short **S** curves caused by irregularities in the rails. By looking over the side, while the engine is moving at high speeds, the boxes may be observed to move with an incessant lateral vibration, while the frame remains steady (thus showing the number and amount of blows which the frame and rails receive in ordinary cases), the friction, in passing round curves, being limited to the coupled wheels, or 8-feet base. This 8-feet rigid base is, however, again greatly eased in passing round curves, by the use of the spring tires, which admit of a slight lateral motion. These tires also give a better grip on the rail, by slightly flattening under the weight of the engine, and thus presenting more surface for friction. As a proof of this, a train of wagons was placed on a curve of 450 feet radius, with a rise of 1 in 78, and two engines—identical in every respect, (except that the wheels of one engine had spring tires,) worked at the same pressure, and driven by the same man—were successively attached to it, when the one with spring tires brought out 15 wagons, and the one with ordinary tires 13 wagons. This result is confirmed by the working of all the engines fitted in the same way.

This engine was completed in the first week of November, 1863, and has been since running regularly, taking its turn of duty with passenger trains, or coal trains, or as a shunting engine, and about the numerous works connected by sharp curves with the St. Helen's line. The motion round curves is free from all jerking, and on straight lines the speed is more than 60 miles an hour, either end of the engine being first, without any train behind to give steadiness, and the motion is so smooth that it has only been by taking the actual time, that Engineers have convinced themselves of the fact of the speed exceeding 40 miles an hour. It was built to traverse curves of 200 feet radius. This it does with the greatest facility, and has regularly worked the passenger trains round a curve of 1,000 feet radius, going directly off the straight line by a pair of facing points, at a speed of more than 30 miles an hour; and it has gone round a curve of 132 feet radius. It has also run a train of twelve passenger carriages, weighted up to 100 tons, exclusive of its own weight, at 60 miles an hour on the level. From the advantages it possesses over ordinary mixed engines for weighting the trailing coupled wheel, it, without difficulty, on a wet slippery day, started and took this load up a gradient of 1 in 70, drawing seven of the carriages with a load weighing 72 tons 5 cwt. up a gradient of 1 in 36, round a curve of 440 feet radius; and coal trains of 250 tons are worked over long gradients of 1 in 200 with the greatest ease. It is evident,

then, that engines on this principle, affording facilities for the use of high power in hilly countries, are peculiarly adapted for metropolitan lines, where sharp curves are a necessity (being equally safe whichever end is foremost), and are also well suited for light lines in India and the colonies. It may likewise be remarked, that carriages and wagons on this principle would carry heavier freights, with a saving in the proportion of dead weight, while their friction round curves would be less than at present.

No. 1,117.—"On the Impedimental Friction between Wheel Tire and Rails, with Plans for Improvement."[1] By WILLIAM BRIDGES ADAMS.

A TRUE cylinder, having a clean and polished surface, may move forwards and backwards on a similar plane, for an unlimited time, without friction, provided the weight of the cylinder be not sufficient to crush, or alter, its own form, or the form of the plane. So also, a true cone moving on a true plane may roll without friction,—with the difference, that while the cylinder can only roll in a straight line, the cone can only move in a circle corresponding to its varying diameter.

A pair of railway wheels fixed on a shaft represent portions of two cones. If, instead of being connected by a shaft, these two cones were prolonged till their largest diameters met in the centre, as a solid body, and were then placed on the plane, their movement would be, to roll in a straight line without friction, supposing them to be balanced on the central diameter; or in circles to the right or left, if bearing on the respective conical surfaces. The fact that a pair of railway wheels are truncated cones, connected by a shaft, does not alter these conditions. The flanges, if of exactly equal diameter, will represent a cylinder, and will roll forward on a plane, in a straight line, without friction.

When such wheels are placed on rails, a new condition arises: the wheels may run on equal diameters to suit a straight line, or on varying diameters to suit curves, provided always that there be sufficient traverse, or play, between the rails to allow sufficient variation of the diameters to suit the varying length of the two rails. If there be not this play, the compensation of the cones is a fallacy, and the movement ceases to be a rolling movement, and becomes a sledging movement, even supposing the rails to be true and accurate segments of circles, with perfect tables and equal bearings.

Thus far with regard to a single pair of wheels; but when two pairs of wheels are connected together to a frame to form a carriage on the usual plan, other conditions arise. If the axles be parallel to each other, and the wheels be in the same plane, the carriage will run without friction on a straight line; but on a curve

[1] The discussion upon this and the preceding Paper occupied portions of two evenings, but an abstract of the whole is given consecutively.

a larger amount of play in the rails would be needed. And there would be yet another difficulty, the rigid construction of the carriage prevents the axles diverging from their parallelism and pointing truly to the centre of the curve,—a condition necessary to the fulfilment of the mechanical requirements. The longer the carriage, *i.e*, the farther the axles are apart, the greater becomes the friction. Supposing that the axles are parallel, but that the wheels are out of plane with each other, then the wheels will become partial, but constant, sledges under all circumstances; and supposing that the axles are not parallel, but at an angle with each other, then also the wheels will be sledges, and will only roll when passing round curves corresponding to the angle.

All this is on the supposition, that a railway is composed of straight lines and curves, with the rails perfectly true and smooth. But in practice the conditions are quite different. Examining the rails closely, there is found to be an incessant alteration of surface across their breadth. Sometimes the bearing of the wheels is inside the rail, and sometimes outside, on straight lines; and sometimes in a series of small curves, changing from one side to the other of the same rail.

The theory of the compensatory action of the coned tires, to accommodate them to straight lines, or curves, can only be based on the supposition, that such tires run on a surface of little breadth —knife-edges. The theory of the rail is, that it should be so pitched inwards, as to keep the table parallel to the cone of the wheels. If it be not so pitched, the engine wheels will soon grind, or crush the rail table down to a corresponding form. This condition will induce friction between the tire and the rail, of questionable utility for the purpose of adhesion in the case of the engine wheels, but certainly mischievous in the case of all the other wheels in the train. In truth, the theory of conic compensation cannot be reduced to practice, in the present state of mechanical railway art. The practical compensation is in the constant change from rolling to sliding movement, when the rolling of either wheel on the same shaft is too fast, or too slow for the length of the pathway,—and the result is impedimental friction.

If proof were wanted of this, it might readily be given in the "glint" on the surfaces of the rails, after the passage of a train; or in the fine black iron dust which adheres to the finger from this polished surface. It is not produced by rolling action, for that leaves a dead and not a bright surface: it is a "burnishing" action, a sliding of surfaces, which induces the bright polish. Another instance may be adduced. It is well known that rails long worn in chairs present, when reversed, a series of notches, of more or less depth, on the rail table, causing an unpleasant jerking sensation to the carriages. Gradually the edges of the notches

become worn down, and the rectangular notches first become small curves, then curves of larger radius, and finally disappear altogether, the rail surface becoming a plane. Theoretically, supposing only a rolling movement, the wear on the curves ought to be equal to the wear on the intermediate portion; and that it is not so, indicates that there has been sliding, and abrading or planing action. On the other hand, railway wheels, after long use, become hollow on the periphery across their breadth, the outside forming as it were an external flange. If the wheel merely rolled, the tire ought to become constantly harder and more solid, as it were "hammer hardened," but practically it is ground away by the expenditure of engine power on impedimental friction. What this may occasionally amount to may be judged of, by a fact recorded by an experimenter on railway machinery, viz., that a train of coal wagons, though without the breaks in action, would not run down an incline of 1 in 75 without the application of engine power.

Goods trains are usually coupled, *i e.*, attached loosely by slack chains from wagon to wagon. A goods driver, when starting his train into motion, first pushes back all the wagons together, one against the other. He then starts the first, and then the second, and so on, getting the whole train gradually into motion. If the train were closely coupled, the engine would only slip the wheels without moving the train. If the train be watched from a bridge, each wagon will be noticed moving on an irregular, sinuous, zigzag path, and independent of its neighbour, save when snatched by the chains. If a passenger train be watched from the same bridge, it will be found to keep an apparently even course. The reason is, that the various carriages forming the train are closely coupled together, with the spring buffers in contact. With loose couplings the carriages would oscillate laterally by their wheels seeking the path of least friction; this would annoy the passengers; therefore steadiness is preserved at the expense of sledge-like movement, additional friction, and steam-power.

But, inasmuch as the conic compensation can only come into action by the lateral traverse of the wheels, and as at high speeds there is no time for such traverse, it follows that a large proportion of the movement along the rails must be sledging instead of rolling. While thus travelling, the action of the unequal path produces a torsion of the axle, which first winds round like a spring, and then, from time to time, is freed by the inequalities of the rails, and induces blows; and as the wheel-tires become hollowed, lateral traverse is altogether prevented, and the rails are severely strained.

It is a common practice on railways to elevate the outer rail on curves, with the object of counteracting, by inward gravitation, the centrifugal force tending to throw the train off the line; and

this is occasionally done to an elevation of 6 inches above the inner rail, on a curve of 600 feet radius, equivalent to an incline of 1 in 9; and consequently, the weight is proportionately heavier on the inner rail, and lighter on the outer rail. Theoretically, the inward gravitation is calculated to balance the centrifugal force on curves, and therefore, at high speeds, the grinding of the flanges ought not to be greater against one rail than the other; and, at slow speeds, the grind ought to be entirely against the inner rail. But the direct contrary is the fact; the inner edge of the outer rail is ground by the wheel flanges, and the top of the inner rail is worn by the tread of the wheel. The reason is, that the inner wheel runs on a larger diameter than the outer, and by the greater weight on it, has more bite than the outer, and consequently governs the whole movement, overpowering the inward gravitation, and assisting the centrifugal force to closer contact with the outer rail. To avoid the destruction arising from these faulty principles of construction, steel is now used both for tires and rails. Better construction would enable iron to do its work at a much less cost however, by imparting a rolling movement in the place of a sledging movement.

Some of the earliest tires were of Staffordshire iron. This iron squeezed and rubbed out under the loads. Different kinds of Yorkshire iron were then chiefly used, such as Low Moor, Leeds, Bowling, Park Gate, and others; but increasing loads rendered these inefficient; and various attempts were made to steel the surfaces of English iron. Krupp's steel became the standard of quality, which Bessemer and others are now endeavouring to equal, if not excel, by a cheaper process. And, though Krupp's steel has not yet been used for rails, Bessemer steel is largely applied on the London and North Western and other lines. Thus, the cost of rails varies from Welsh iron at £6 per ton to that of Bessemer steel at from £16 to £20 per ton. And the cost of tires varies from Staffordshire iron at £10 per ton to Krupp's steel at £70 per ton.

One great mechanical difference between iron and steel is, that the former is manufactured from a number of pieces, imperfectly welded together, with scale between the welds, making it all more or less 'scrap iron,' and liable to separate into parts under blows and pressure. Steel, on the contrary, being cast into one homogeneous mass without welds, is not subject to disintegrate, and is sufficiently hard not to rub away easily. Yet there are circumstances under which it does wear away more rapidly than iron. A number of steel-surfaced tires, which were used on a line through a sandy district, had been hardened and ground to a face; but these tires wore out faster than iron tires upon the same line. The reason was plain; the blowing sand bedded itself in the substance

of the soft rails, but acted as a grindstone on the hard steel, precisely like an emery stick.

It was after a long study of these facts, that the Author turned his attention to the possibility of a remedy. An obvious one was the loose wheel; but this involved alterations in structure, increase in the number of parts, provision for lubrication, and amongst other conditions, to get elastic resilience as close as possible to the percussive action between tire and rail. A spring-wheel was the next suggestion; but spring-wheels had been experimented on many years before, with the result that a spring frame to a wheel did not answer; and thus arose the question, whether it was not practicable to make a spring tire that would accommodate itself to every variation of surface, like a horse's foot?

A loose tire is one of the things denounced as a source of danger on railways, and to be carefully guarded against. It is most dangerous in the case of a tire fastened with through bolts or rivets, because it indicates that the tire has lost the condition of a true circle, and has become a ring of many segments, constantly striking blows. But a tight tire is also a source of danger, by reason of its tendency to burst, especially in time of frost. The Author, therefore, came to the conclusion that a tire neither loose nor tight, but fitting elastically to the wheel, was the safest of all, as there can be no tendency to burst, with sufficient yield to prevent the mischievous effect of blows, as a result of keeping constantly in contact, while a slightly pliant surface induces a better adhesion of the driving wheels, and freer movement of the train wheels. There is an apparent objection to change of form in the circle of the tire, but not if the tire be elastic.

Being satisfied of these conditions, the Author devised the following plan. A tire with a deep front rib was bored out internally to a cone, parallel to the tread of the tire; this cone was hollowed out to a depth of a quarter of an inch, leaving a flat edge of three-eighths of an inch on each side. On this was laid a hoop of spring-steel, tempered. The periphery of the wheel was then turned to a curve across the breadth, corresponding to the curve in the tire. Into the cone formed by the spring the wheel was pressed, with a force equal to three bolts of one inch in diameter, and confined there by a flat ring, sprung into a grove in the back of the tire. The Author was satisfied with the principle and the mechanical arrangement; but there remained the great difficulty of persuading Engineers of the advantages of the system. At length an opportunity for making the experiment was conceded. A set of wheels was selected of the class known to be the most destructive to tires—solid discs of wrought iron—which by their rigid action crushed the metal on the rails. The peripheries of the

wheels were turned to a curve; the hoop spring below was $\frac{5}{16}$ths of an inch thick, and $3\frac{1}{2}$ inches wide. The tires were of Staffordshire iron, with a deep front rib, and a false rib, or flat ring in a groove at the back. The wheel was forced in on the steel hoop by the pressure of two bolts, each one inch in diameter, and the flat ring was sprung into its place, with elastic expansion. This set of wheels was applied to a heavy carriage on the North London line, and ran upwards of 106,000 miles without being turned up, and with scarcely any perceptible difference in their surface, the flanges being absolutely unworn; while Low Moor tires, under the same conditions, were heavily worn, both in flange and tread.

On another line, the four coupled wheels of a six-wheel engine were fitted with similar tires, which ran about twelve months. These were very imperfect. The tires of Staffordshire iron, badly made, were reedy, and separated into strips. The springs were in single layers, were too weak for the work, and had to be replaced; but some remarkable facts were developed. The tires, when so loose as to be moved round the lifted wheel by hand, in fact having a $\frac{1}{4}$-inch play, were found equally efficient in adhesion and draught. The tires did not slip on the rails, but the wheels did slip within the tires, just sufficiently to compensate for the difference in length of pathway round sharp curves. Finally, however, this engine was broken up, the boiler being too old to be used with safety.

On the same line, on curves where the wear on the leading wheels of the engines was so severe that with new wheels, after running only 9,000 miles, the flanges needed "turning up," a pair of Leeds tires was applied with springs, and ran 25,240 miles before "turning up" was required. At the same time, a similar engine was contrived with a "bogie" for the leading axle to traverse upon curves, so as to give abundant lateral traverse to the wheel cones, with the same quality of tires, and the result was, that the spring tires, without this advantage, gave an equally good result.

This new system of wheels, but with double instead of single spring hoops, was applied by Mr. Cross, the Engineer of the St. Helen's Railway, Lancashire. This line is one of the most remarkable for its heavy gradients and sharp curves; the gradients being 1 in 35, 1 in 70, and 1 in 85, while the curves are of 300 feet and 500 feet radius; and moreover the points and crossings are very frequent, 12 miles of sidings occurring in a distance of 2 miles from the St. Helen's station, the total length of the line being 30 miles.

Mr. Cross states, date September 4th, 1861, that—

"The tires are giving great satisfaction. I had them made of

common Staffordshire iron, and put under a six-wheeled coupled engine, weighing 21 tons, and they have now run 29,429 miles with heavy trains. On this line the gradients are all heavy, with the sand constantly in use, yet the wear has been very slight. I am so satisfied, that when I get a new locomotive, I shall have similar tires."

From a tabular statement[1] of the performance of four classes of tires on the St. Helen's Railway, compared with each other, viz., Krupp's Steel, Swedish iron, Hood and Cooper's best Yorkshire iron, and Staffordshire iron, with springs between the tire and the wheels, it appears, that Swedish iron (Engine No. 27) has less than three-fourths the durability of Hood and Cooper's Yorkshire ; that Krupp's Steel has run twice the distance of Hood and Cooper's ; and comparing Staffordshire tires with springs (Engine No. 18) with Krupp's Steel (Engine No. 23), it appears that the former has two more coupled wheels, $\frac{1}{9}$th less in diameter, $\frac{1}{13}$th more weight, has run $\frac{1}{3}$rd more mileage, scarcely ever slips, and that the tires have not been turned up, or needed it. The total distance run by the Staffordshire tires before reducing the flanges was 63,913 miles, as against Krupp's 40,843 miles. But, inasmuch as Krupp's steel tires were 4 feet 6 inches in diameter, and the spring tires were only 4 feet in diameter, credit must be taken for one-eighth more revolutions in the latter, making the distance run by the latter equivalent to 71,902 miles, as against 40,843 miles of the former.

The sections, Plate 8, Figs. 1, 2, and 3, show the wear of three out of these four different classes of engine tires ; all the templates of the wear being taken from plaster casts. It will be perceived, that with the exception of reducing the depth of the flanges, the spring tires do not need turning up, and apparently may be worn out without turning up save the reduction of the flanges.

That wear occurs at all is, however, an indication that yet more is required in principle. It should be observed, that the tires most worn on the six-wheeled coupled engine are those with the smallest load. The reason for this apparent paradox is, that the load on the leading wheels is probably not enough to give adhesion on

[1] Comparative Wear of four classes of Engine Tires, on the St. Helen's Railway Lancashire, demonstrating the superior economy of Spring Tires :—

No. of Engine.	No. of Wheels.	Do. Coupled.	Diameters of Wheels.	Weight.	Miles Run.	Slip of Wheels.	Remarks.	Class of Tire.
			ft. in.	tns. cwt.				
23	6	4	4 6	19 15	40,843	Slipped	Needing turning up.	Krupp's steel.
4	6	4	4 6	20 6	20,798	even in dry	Ditto. [once.	Hood and Cooper's best
27	6	4	4 6	23 14	34,006	weather.	Do. and been turned	Swedish iron.
18	6	6	4 0	21 0	55,138	Scarcely ever slip.	Never turned up, nor needing it. [up.	Staffordshire iron, with springs between the wheel and the tire.
					71,902	.. ..	Before being turned	

the rail, and to force the wheels to slip within the tires for compensation, which the more heavily-loaded wheels do.

The principle needed, in addition to the moving tire, is that of radiating axles. The flanges of the spring wheels are saved from wear on curves, partly by slipping round, and partly by horizontal rocking on the curved periphery of the wheel. The flange of a rigid tire acts as a shearing machine; it cuts the rail, and is cut by the rail. The flange of a spring wheel, if it touches the rail, yields and springs up, while the tread fits itself to all inequalities of the rail. But the spring tire, in common with the rigid tire, is occasionally obliged to slide across the rail-table laterally, and this action is mischievous, though in a less degree.

As early as the year 1835, this defect in structure was noticed by the Author; but till the year 1861 no plan of the many he devised could be made to accommodate itself to the old systems; all, however, had reference to the radiation of the axles on curves. It may be in the recollection of some Engineers, that the Author was the inventor of a spring, known as the 'bow spring,' which gave free elastic action in every direction, saving the frame from blows, by permitting the wheels to recoil laterally, and fore and aft, and diagonally, with a perfectly easy vertical motion. These springs were used without axle-guards, as the latter impeded the action of the springs, and caused noise. The absence of the axle-guards was objected to as involving risk, but the direct reverse was once proved in a remarkable manner. An engine ran into a train of empty carriages on a siding, some of the carriages being on bow springs, without axle-guards, and some on common springs, with axle-guards. The result was that the axle-guards were, in several vehicles, broken off, by sudden contact with the boxes and wheels, while the bow spring vehicles sustained no damage. On another occasion, where a shed-roof fell in on a train, some of the carriages were saved from damage by their elastic bow springs, but the others suffered.

While experimenting with a bow-spring carriage, it was noticed that, though generally easy and free from excessive vibration, there, from time to time, occurred a hard and unpleasant grinding. This always happened on curves, and the reason was obvious: the front wheel on the outer rail, and the hind wheel on the inner rail, were brought in forcible contact with their flanges; and consequently recoiled, forcing the axles in the opposite direction to that which should have been assumed, viz., at a tangent, instead of radial, to the centre of the curve. To have applied axle-guards would have modified, but would not have corrected the evil; the absence of guards exaggerated it. The true position for the axles on the straight line is parallel to each other, with the wheels all in the same plane, and of the same diameter on each axle. On a

curve every axle should point to the centre of the curve, and the coned diameters of the wheels should vary in proportion to the width of the gauge. In the construction of a turntable, manufacturers regard this condition; but in an engine going round a curve, which is only an enlargement of the same action, the principle is disregarded. So also, in the ordinary "bogie" system of four wheels, the mechanical principle is imperfect, the leading wheel strikes its flange against the outer rail, the trailing wheel strikes its flange against the inner rail, and the bogie becomes more or less of a sledge; and this action is exaggerated by the action of the driving wheels, which tends to force the bogie on to the outer rail.

After some thought, the Author discovered a means of causing the axles to radiate on curves, so as to insure their pointing to the centre of the curve. The axle-boxes, as applied to the ordinary wheels and axles, are supplemented with flanges, fore and aft, in curved lines, the curves being struck from central points between the axles. The axle-guards, or horn-plates, are faced to the same curves. Therefore when the flange of the front wheel touches the outer rail, the boxes slide laterally, and being only able to slide on a curved line, the axles and boxes retained in the axle-guards must point to the centre of the rail curve. The tops of the axle-boxes can also be formed in a curved line. In the centre of each box the spring-shoe rests, and therefore, on a straight line, the axle will be at a right angle, and can only leave that position by the pressure of the wheel flanges right or left of the curve. Thus the engine, or carriage, can run equally well on a straight line, or on a curve.

An engine was set out by the Author on eight wheels, of which four were coupled drivers in the middle, and the other four were, two at each end, on the principle of radiation just described, and this design was forwarded to St. Helen's in the year 1861. In October, 1862, Mr. Cross wrote, that he had given orders for the working drawings for an engine to be made, and felt confident of success, though the design might afterwards be capable of improvement.[1]

Having accomplished such successful results with spring-tires, the Author's attention was next turned to the possibility of a similar result in giving elasticity to the rails; as, supposing other things to be

[1] By the application of friction wheels between the drivers and the radial wheels —a plan which has been demonstrated to answer in practice with an ordinary engine—the four radial wheels become coupled-drivers, without interfering with their radial action: and a ten-driver, radial tank-engine may thus be constructed, carrying 2,500 gallons of water and rolling round curves of three chains radius.—W. B. A.

equal, and action and reaction to be equal between rails and tires, it follows, that the saving and economy in tires must be followed by equal saving in the rails. Most Engineers insist on the necessity of elasticity in the permanent way, but to be of any value, that elasticity must be uniform, and not a system of alternate elasticity and rigidity, in which the elasticity serves to aggravate the rigidity by a succession of jumps. The line least subject to destruction would be that which is floated on the surface of a bog; but this would involve surplus engine power, by a constantly rising incline in front. To make such a line perfect, the superstructure should be very stiff and inflexible; as, for example, a continuous ship's deck with deep rails fastened on it. A permanent way on the broad-gauge system, with longitudinal timbers, probably does not deflect much into the ballast, but the shallow rail fastened on it bends under the wheel and deflects into the timber; and though the timber is not a rigid body like stone, this system does not fulfil the condition of an elastic way. Neither does the narrow gauge, with its rails in chairs, and its chairs on transverse sleepers, fulfil the elastic condition. The rails cannot well deflect elastically on the three-feet length from chair to chair, and ballast, if not solid and rigid, is plastic and not elastic. The timbers are called sleepers in imitation of the builder's term, but are not sleepers in the builder's sense, for railway sleepers do not rest as timber does under a wall, but spring, and like bad walls require constant "underpinning" by the process called "packing," which the running of the trains constantly unpacks, by rolling and displacement—the longitudinals laterally, and the transverse fore and aft.

The first consideration in a permanent way is to get a firm and unyielding foundation, a very difficult thing with loose porous ballast, and also with clay or earth to which water has access. Could the surface be covered with flag stones tightly-jointed, like London pavements, the process would be easier; for ballast, intended to let the water out by the same process as the entrance, is a very inefficient arrangement. Paving the surface of a railway of small traffic might be costly at the outset; but ballasting a London street would be a far more costly thing in repairs. There can be no doubt also, that it would be far cheaper to pave brickwork viaducts, like the Blackwall and Greenwich, than to ballast them, with the liability to push out the retaining walls with the working of the trains.

That a rigid way is destructive there is ample evidence, for the granite walls of Jesse Hartley broke up rails and tires; and whenever frost sets in, and the way is rock-bound, rails and tires still break; but if an elastic way were placed on the granite wall, or rock-bound way, nothing could be better. As it is, the non-elastic

superstructure disintegrates the plastic substructure, or hammers it into a rock or an arch, on which the sleepers are not level packed, but roll fore and aft.

On the passage of trains, every sleeper in succession sinks under the pressure of each wheel; the fish-joints bend and spring back; the rails rise and fall in the chairs with a clattering noise, and the wooden keys shake backwards and forwards, being retained chiefly by the ballast. The rail is bent and pressed on the chair, and the chair is pressed on the sleeper, and the sleeper strikes a blow on the ballast. It is therefore evident, that with a spring of sufficient power under the sleeper, there would be no blow. This would be a difficult mechanical arrangement, but there is another method of accomplishing the same thing—taking up the rails and chairs, and fastening longitudinal timbers upon the transverse sleepers by spikes, and then replacing the rails and chairs; and spacing the chairs on the longitudinal timbers intermediately to the transverse sleepers. This plan has been tried on the North London main line. The rails were fixed to the longitudinal base by cast-iron brackets, bolted to and through the rails, leaving a distance of an inch and a half between the lower table of the rails and the longitudinals, which, not being packed below, formed a uniform elastic base without any hard points. A short length, laid in January, 1862, during rain, has never been touched, and, according to the report of the Superintendent, the sleepers show no signs of movement, under a traffic of 120 trains per day, conveying passengers, coal, and goods, the express trains running at a speed of between fifty and sixty miles per hour. The drivers consider it is the best part of the line, the sensation being that of passing over a new line well made before the ballast has got hard. It is obvious that the pressure of the wheels never comes on a single sleeper, as in the ordinary system. Each wheel in succession distributes the load over two or more sleepers, through an elastic medium, and the cross sleepers, being fast to the longitudinals, do not move at all.

Some years back a portion of the Great Western Railway was laid upon a plan which was similar in appearance, inasmuch as longitudinals and cross sleepers were used in juxta-position; but it was not found to answer, for both were packed alike, and the rail used was the flexible bridge rail, with a continuous bearing, not in any way inducing elastic resilience. The object in using the cross sleeper was simply to form a better framing than the cross transomes abutted at their ends, but the increased difficulty in packing caused it to be abandoned.

The system on the North London line has several obvious advantages. First, it forms a framing, the longitudinal basis keeping the cross sleepers in position, without fore and aft rolling or side movement, tending to make the line crooked. Secondly, each

sleeper gets only half the work, as the load of each wheel is distributed over two or more sleepers at once. Thirdly, the rail bears through its whole length only on chairs, standing on an elastic base, and thus the elasticity is equable and continuous, and not disturbed by blows. For this reason the more firm the bearing beneath the sleepers, the better is the condition of the line.

Many superintendents have great objections to timber as a destructible material, uncertain and troublesome; and it may be objected to this system, that as the longitudinals are extra, it increases both the first cost and the cost of maintenance. Timber is no doubt destructible, with more or less rapidity, according to the conditions under which it is used. It is most destructible when it is partially buried. If quite buried in ground always moist, it is durable. If kept altogether out of the ground it is also durable, at any rate in climates like that of England.

With this system of longitudinal elastic bearers it is quite practicable to keep the timber wholly out of the ground, using as sleepers metal, or stone, not subject to rot. The cost of a first-class cross-sleeper road may be tabulated in quantities per mile as follows:—

	lbs.	Tons.	Cwts.	£.	£.
504 rails .	at 84 per yard,	132	0	at 8 per ton,	1,056
4,224 chairs .	„ 42 each .	79	4	„ 4 „	317
8,448 spikes .	„ 1 „ .	3	16	„ 12 „	48
2,016 bolts .	„ 1½ „ .	1	7	„ 20 „	27
1,008 fish-plates	„ 22 per pair .	5	0	„ 9 „	45
	Tons .	221	7		

	Ft.	In.	In.	In.	Ft.		
2,112 cross-sleepers	2	6 apart,	5	× 10 ×	9, at 4s. each		424
4,224 keys						1½d. „	27
							£1,944

Upon the elastic system, the sources of destruction are so far removed, that the excessive weights rendered needful by rigidity are not required; nor is it necessary to place the cross sleepers so close together: the quantities per mile will therefore stand thus:—

	lbs.	Tons.	Cwts.	£.	£.	s.
504 rails .	at 72 per yard,	113	3	at 8 per ton,	905	0
3,520 chairs .	„ 28 each .	44	0	„ 4 „	176	0
7,540 spikes .	„ 1 „ .	3	3	„ 12 „	37	16
2,016 bolts .	„ 1 „ .	0	18	„ 20 „	18	0
1,008 fish-plates	22 per pair .	5	0	„ 9 „	45	0
	Tons .	166	4			

	Ft.	In.	In.	Ft.			
1,760 cross sleepers	3 apart,	5	× 10 ×	9, at 4s. each .		352	0
3,520 keys				„ 1½d. „ .		22	0
1,174 longitudinal timbers		5	× 10 ×	9, „ 4s. „ .		287	0
					£1,842	16	

Thus it appears, that the elastic system costs less than the ordinary system. Reasoning analogically, as the effect of elastic springs upon tires of Staffordshire iron is to make them more durable than the best steel, the effect of imparting elastic action to the rails should be a proportionate economy. Iron rails should become more durable than rails of steel used under the ordinary conditions. If so, and taking into account the further durability gained by the adoption of the cross-framed structure, the saving in maintenance should amount to a considerable sum annually.

But longitudinal timbers out of the ground would be inadmissible in hot climates, and metal must be resorted to. Yet metal, as commonly used, is rigid, and therefore objectionable. Hence it is important to ascertain, whether it be not practicable to construct a railway which, though wholly of metal, shall be elastic. The Author thinks it can be accomplished. The sleeper may be of cast iron, with flanged bearers, on the surface of the ballast, and a hollow descending keel. At the bottom of the keel, internally, may be placed plates of tempered steel, curved on the surface, to take the lower table of a double-headed rail. The edges of the steel plates resting on ledges, would have a very small amount of play allowed, but sufficient to take off the jar. The rail could be kept in position at the upper part, on the inner side, by the flange of the sleeper, and on the outside by a key of metal, with a space below the upper table. The rail could be held down by a round iron pin, passing through sleeper and rail, below the bearing flanges. The section of the sleeper could be arranged that, in case of the springs breaking, the rail would directly take a bearing on the sleeper. The distance between sleeper and sleeper would be 18 inches, or two inches less than that in a cross-sleeper road, with the sleepers 2 feet 6 inches apart from centre to centre. The cost of this line would be as follows :—

	lbs.	Tons.	Cwts.		£.	£.	s.
504 rails	65 per yard,	102	3	at	8	817	4
3,018 sleepers 2 × 1 2 (Ft. Ft. In.)	70 each	94	7	„	4	377	8
1,509 angle-tie bars	14 „	9	9	„	9	85	1
3,018 hook-head bolts	1 „	1	7	„	18	24	6
3,018 iron-angle keys	2 „	2	14	„	12	27	8
3,018 round ditto	1 „	1	7	„	12	16	4
6,036 steel plates 3 × $\frac{3}{8}$ × 6, (In. In. In.)	2 „	5	8	„	25	135	0
1,008 fish-plates	22 per pair	5	0	„	9	45	0
2,016 bolts	1 „	0	18	„	18	16	4
	Tons	222	13			£1,543	15

In India the traffic is not so heavy, generally, as at home, and a rail of 65 lbs. on springs would be more durable than a rail of 75 lbs. on ordinary rigid cast sleepers. The bearing area would

be about 8,000 square feet per mile, and, being upon the surface, would be packed easily and with great steadiness, by reason of the base being near the rail head; and besides, the depth of the keel, together with the broad angle iron, would keep it fast down.

It may be objected, that springs are apt to break. This is quite true if the springs are not carefully made, and if subjected to the action of frost. But there is no frost in India; and if the springs do break, the rail simply rests directly on the sleepers, upon an area four times as great as that of the ordinary sleepers. This line can be arranged for extremely sharp curves.

As the result of the North London experiment shows that timber longitudinals, for the purpose of continuous elastic action, are effective, it becomes desirable to apply them on sleepers that are permanent, which a system of iron cross sleepers, divided into two parts, and connected with short centre tie bars, would effect. The sleepers may be bolted to the longitudinals, so as to be unable to move, and, as their form may be that of a spreading trough, inverted, with a flat top, the packing would then be very easy, length-long, and the sleepers would key into the ballast and hold the line down. Ridges cast on the sleepers would hold the timbers, with play to key them and adjust them, so as to make the gauge of the way exact. The cost of this line would be as follows:—

	lbs.	Tons.	Cwts.	£.	£.	s.
504 rails . .	72 per yard,	113	3 at	8 per ton	905	6
3,520 chairs . .	28 each .	44	0 „	4 „	176	0
3,520 clips . .	2 „ .	3	3 „	12 „	37	16
1,008 fish-plates .	22 per pair .	5	0 „	9 „	45	0
2,016 bolts . .	1 each .	0	18 „	20 „	18	0
3,520 cast-iron sleepers	70 „ .	110	0 „	4 „	440	0
	Ft. In. In.					
1,174 longitudinals	9 × 5 × 10, at 4s. each				234	16
3,520 wood keys	$1\frac{1}{2}d.$ „				22	0
					£1,878	18

From which it would appear that, even with elastic longitudinals and permanent metal sleepers, this line costs rather less than the standard first-class permanent way.

It is now two years and three months since this piece of elastic way was first laid down on the North London Line. It is still in the same good condition, and has never been opened out, or packed. On the wearing-table the surface shows no distress, and scarcely any wear; while the neighbouring rails on the rigid system betray the usual amount of destruction, from three to four years being the life of a double-headed rail of 82 lbs. per yard. It appears that the elasticity which is obtained, both laterally and vertically, eludes the blows of the wheels, and prevents that disintegration of the metal which takes place, under rigid action, at the

imperfect welds of the ordinary iron rails. There is a remarkable confirmation of this in the fact, that the two rigidly connected ends of the rails are split in the usual manner, while on the elastic portion the same rails are undamaged. In this piece of line, the cross sleepers are 3 feet apart, and so remarkable has been the result, that the superintendent, Mr. Matthews, has laid down a further length on the Poplar line, with the cross sleepers 6 feet apart, and with two rail supports in the elastic space between. The longitudinals are 4 inches deep, by 11 inches wide. Theoretically, this should be a better road than a rigid one with the cross sleepers 3 feet apart, for the load being distributed over two sleepers through an elastic medium, the strain will be less severe. If the result be favourable, there will be only ten loads of timber per mile beyond the ordinary cross-sleeper road.

The conclusions that the Author has arrived at, are—

1st. That the chief sources of destruction in rolling stock and permanent way, apart from disproportionate weight, are blows and friction between tires and rails, producing jumping and sliding.

2nd. That the best mode of preventing the blow, is to provide for elastic resilience immediately over the tire, beneath the wheel, and immediately under the rail, taking care that the rail in itself should be as rigid as possible, while the rail-joints are elastically supported by fishes of sufficient depth. This continuous elasticity can, however, only be obtained by discontinuous supports, as with the double-headed rail on an elastic base; the flat-footed and bridge rail with continuous support are not adapted for it, but can be applied with dis-continuous supports.

The question of rail-joints is so important, that the Author is desirous of making it well understood. The original fishes, which he proposed, were driven in on each side of the rail, between two chairs placed on two sleepers; the distance between the chairs being only 6 inches. In this mode parallel fishes might serve the purpose. But when bolted fishes were adopted, the distance between the chairs was necessarily widened to 2 feet. Under these circumstances parallel fishes were an obvious mistake; but they were persevered in, because they were easily produced by rolling. To make a joint perfect, the strength should be as great at the joint as at the intermediate portions of the rail; but, inasmuch as the rails are 5 inches in depth, and the ordinary fishes little more than $2\frac{1}{2}$ inches, theoretically the joint ought to bend, and practically it does bend, as the wheels pass over it. To compensate for want of depth, the fishes have therefore been increased in thickness, with very little advantage in point of strength, and with great disadvantage in point of manufacture, inasmuch as the greater thickness and increased size of the bolt holes causes distortion in punching, and want of true fit. The bolts have been enlarged in

the hope of thereby keeping the fishes tight. Theoretically the fish fits between the rail tables as an obtuse wedge, and it is supposed to slide between the tables, and take closer contact as the bolts act. This may be the case when first applied, but after a short use, both fishes and rails become indented, and the sliding power is at an end, and no amount of bolt power can then hold them tight. To remedy this evil, the first consideration is so to deepen the fishes as to give them equal strength with the solid rails at the joint; secondly, to give them fixed, and not sliding abutments against the rail tables, and to tighten them by an elastic expansion with the bolt power. The plan is shown in Plate 8, Figs. 6 and 6A. The fishes are formed with inner ribs, which fit accurately between the rail tables. The outer fish on the top rises to the level of the rail and descends below it, giving a greater depth. The inner fish fits under the upper table and descends below the lower table. In order to apply the strength only where wanted, the fishes are tapered in depth towards the ends, and they are arched laterally, so that they expand in the channels with elastic pressure by the power of the bolts, and the bolts are kept tight by this elastic action and may be made smaller. It is obvious that no distortion of form will take place in punching; and there is another advantage, in great additional lateral strength, by the lateral projection of the fishes.

3rd. That the sliding, or frictional movement of the tires on the rails can only be completely guarded against, by permitting each wheel to revolve separately, or by permitting the tires to slip on the wheels, and at the same time providing for end play of the axles between the rails, in such a mode that the rails may govern the flanges, and keep the several axles at right angles to the rails, whether on straight lines or on curves.

4th. That the sleepers, or foundations of the permanent way, cannot be too firmly or too rigidly bedded, and that durable iron, or stone blocks, as in the original system, may be advantageously substituted for timber, if elastic resilience be provided.

After many trials, the best arrangement for the spring tires has been found to be, a spring tapered in width from the edges, increasing to the centre, the wheel being a true cylinder on the edge, and the tire corresponding to it, with a broad groove below, as shown in Plate 8, Fig. 5. The wheel is thus easily applied. It should be understood, that the elastic action both in the wheels and the rails increases in importance with the speed; but wherever curves exist, it is of great importance that the revolutions of the tires should correspond to the length of rail. Plate 8, Fig. 4, shows a plan in which a plain steel band is interposed between the wheel and the tire, suffering the wheel to slip round in the band, or the tire to slip round on the band. This is the equiva-

lent of a loose wheel with cheap and simple structure, compensating on curves.

When speeds are not excessive, rigid way may be constructed; but in such cases it is essential to have as nearly as possible a continuous bearing for the rail. A simple plan for this purpose is shown at Plate 8, Figs. 7 and 7A. A series of cast-iron troughs, with broad flanges bearing on the surface of the ballast, are spaced at distances of 3 feet apart from centre to centre. In the troughs are placed single-headed rails, keyed down by round pins, two to each sleeper, the sleepers being each 2 feet long. They are connected from side to side by tie-bars, which keep the exact gauge. There is no timber in the whole structure, and the weight of metal in a mile is under 180 tons, as follows:—

			Tons.	Cwt.
3,520 yards of rail,	21 feet long,	45 lbs. per yard . .	70	14
3,520 sleepers,	2 „	60 „ each	94	6
1,760 tie bars,	4 ft. 8½ in. „	14 „ „	11	0
8,048 round keys,	1 ft. . „	⅝ „ „	2	14
3,520 hook-head bolts,		10 oz. „	1	0
			179	14

No fishes are required, the ends of the rails being secured in the joint sleepers by four keys of round iron. This line, in conjunction with revolving tires, would be very effective for moderate speeds, and it is well adapted to lay down, especially for sharp curves. The trials made have been quite satisfactory.

The Paper is illustrated by a series of diagrams, from which Plate 8 has been compiled.

[Mr. C. H. Gregory,

Mr. C. H. Gregory, V.P., said, he had listened with much interest to the two Papers before them, and not with any the less interest because the inventions brought under their notice emanated from a gentleman whom he had known for twenty-five years as having devoted himself earnestly and honestly to railway improvements. He believed that Mr. Adams's labours had been of great value to the railway world, and the merit of one of his former inventions, the fish-joint, was now universally admitted.

With regard to the introduction of a spring between the tires and the frames of wheels, the facts brought before them seemed conclusive, as to the diminution in the wear of tires, effected by the introduction of the spring between the tire and the body of the wheel; and he should watch with interest the further use of the spring, which would show whether its advantages were counterbalanced by any evil which had not yet become apparent. Hitherto a loose tire had habitually been looked upon as an element of danger; it was true, that evil had generally been associated with a defective mode of fastening, and therefore it was possible that the loose tire coupled with a good fastening might not be objectionable.

He considered the radial axle, when properly applied to locomotive engines, to be a very valuable invention, which might be adopted without any fear; and this conclusion was formed not merely from an inspection of the drawings, but after carefully watching the working of an engine fitted with the radiating axle-boxes.

A long wheel-base had been found of advantage in affording capacity for large engine power; but that advantage had been hitherto diminished more or less by the retarding effect of friction. Length of wheel-base, while giving increased steadiness when running at high speeds on a straight line, involved so much friction on curves, as practically to prevent the introduction of engines with long wheel-bases on railways with very sharp curves, where the existence of steep gradients might make powerful engines especially necessary. It had been the custom to consider, that the cone of the wheels gave them freedom of action in going round curves. He believed that view was a fallacy so long as the axles were rigidly parallel. He had seen this fallacy demonstrated with a model carriage, having two pairs of wheels fixed on parallel axles, the diameters of the wheels on one side of the carriage being less than those on the other side. This model carriage being placed on a board, and one end of the board lifted until gravity caused the carriage to run down, it was found that the carriage ran straight, and not, as might have been expected, in a curve. In fact, so long as the axles were rigidly parallel, that parallelism of the axles

Fig 1
ENGINE N° 23 KRUPP'S STEEL TIRES.
The dotted lines denote the wear
4 0 diameter

Driving Tires, load on pair 9T 18Cwt

Leading Tires, load on pair 7T 17Cwt

Fig 3.
ENGINE N° 18. STAFFORDSHIRE IRON TIRES.
With Springs between the Tire and the Wheel
The dotted lines denote the wear
4 0 diameter

Trailing Tires, load on pair 3T 6Cwt

Driving Tires, load on pair 7T 16Cwt

Driving Tires, load on pair 7T 16Cwt

Note.—The Trailing Tires with the lightest load are most worn.

Fig 2
ENGINE N° 4 HOOD AND COOPER'S BEST LEEDS IRON.
The dotted lines denote the wear
5 6 diameter

Leading Tires, load on pair 8T 10Cwt

Driving Tires, load on pair 9T 0Cwt

Fig 4.
ENGINE SPRING-TIRE

Fig 5.
WAGON WASHER-TIRE.

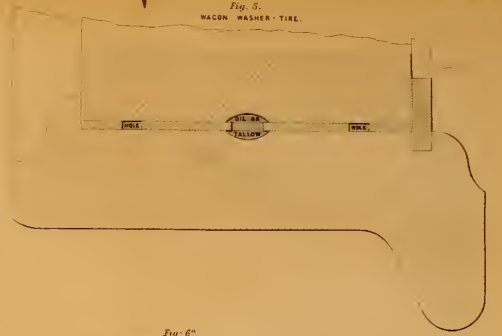
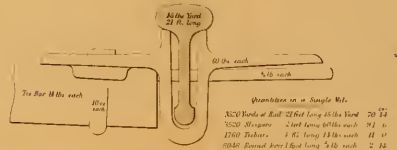


Fig 6a
IMPROVED FISH PLATES.

Fig 6
SECTION OF FISH PLATES

Fig 7.
SECTION OF PERMANENT WAY



Quantities on a Single Mile.

3520 Yards at Rail	21 feet long	65 lbs Yard	70	14
3520 Sleepers	2 feet long	60 lbs each	94	13
1760 Tichars	1 ft. long	13 lbs each	11	17
10560 Round key	1 foot long	5 lb each	2	14
10520 Bolt & nut		10 cs each	1	0
		Tons	179	14

Fig 7a
PLAN OF IRON PERMANENT WAY

Scale ½ Inch = One Foot

would lead to a tendency to run in a straight direction, and the cone of the wheels was of no service in helping an engine round a curve. In order to make the cone of service for such a purpose, the axles must be made to radiate. He thought this plan of Mr. Adams's, when applied to an engine, attained this object more satisfactorily than any other method he had seen. The bogie frame, so successfully adopted in America (from the suggestion, he believed, originally of Mr. Robert Stephenson), and which had been adopted with advantage on many railways in England, to a certain extent obviated the evil arising on curves from rigidly parallel axles, when used with a long wheel-base; but at the same time the partial radiation of the bogie depended upon flange action, and the engine being supported on the bogie, through a centre-pin, there was not the same lateral steadiness of the ends of the engine which could be attained by a system in which the weight of the engine was supported through the side-frames on the ends of the axles, as in the engine under consideration.

Again, another advantage of the radiating axle, as compared with the bogie, was its greater simplicity, and its smaller weight and smaller cost. The expense of the bogie had, in some cases within his knowledge, prevented its adoption, while the cost of the radial axle-box was comparatively small.

He had attended the trials of the 'White Raven,' fitted with Adams's radial axle-boxes, on the North London Railway, and he rode on the engine and watched the working of the axles with great care for some time. During a portion of that time they ran upon very sharp curves, and at high speed, very nearly if not quite 60 miles an hour. The motion going round curves was extremely easy. There was none of the grinding that would have taken place with an ordinary engine having a wheel-base 22 feet long, not fitted with some compensating arrangement; still less was there anything like a blow; and he was led to believe, from subsequent examination of the flanges of the wheels, that they had very little work to do, but that generally the cone of the wheels came into action and brought the axles into their proper position. After the trial had been completed, he observed that the dirt was only just rubbed off the flanges of the wheels, and there was no appearance of anything like severe friction. He had anticipated that, while working well on curves, there might be a tendency for the wheels to run wild on straight lines; but in practice he had not observed any such tendency, and he believed that the engine would run steadily and safely at high speeds on straight lines as well as on curves. When running at high speed on straight lines, he had watched the working of the axle-boxes from the side of the engine, and the only time when he saw a slight motion in the boxes was when they came to a crook, to

which the wheels instantly and easily adapted themselves, without any motion being felt on the engine.

Having mentioned these practical results, he would only add, that he considered that this invention would turn out to the advantage of those railway companies who adopted it.

In reply to an inquiry, Mr. Gregory stated that he thought that the radii of the curves through which they ran at high speeds were about 20 chains; but some of those through which they ran at moderate speeds were very much smaller. The speed on some parts of the line was about 60 miles an hour.

Mr. Vignoles was happy in being able to corroborate, in almost every respect, what had been stated in commendation of the improvements which constituted the subject of the Paper; and the more so, because he thought the railway world was deeply indebted to Mr. Adams for a great number of valuable inventions, of which the public had had the advantage, but which had not always resulted in equal benefit to the Author. He was glad to see that the most useful, practical, and simple invention of the radial axle-box had been brought into use, and he hoped to learn that it was becoming extensively adopted.

He was present at the trial just spoken of, and could state his full conviction, that the action of the machinery realised even more than could have been expected; and he was quite satisfied, that there was no recent improvement in locomotives which was likely to be more beneficial than this one, particularly upon the modern system of adopting very sharp curves. With respect to the supposition, that the cone of the wheel was of service in going round a curve, he was convinced that it was quite a fallacy, and that the cone, in its simple form, was only a counteraction of the oscillating motion in an engine, when moving in a straightforward direction, and that its tendency was simply to throw the flange of the wheel from off the rail. He believed that all practical men were agreed as to that point. He was also of opinion, that the application of the radial principle would, in some respects, bring the cone into play, by throwing it through gravity into that particular action for which it was most suited.

With respect to the bogie, as originally applied in America, it was a useful invention; but his practice had proved to him, that the single bogie was even more efficient than the double bogie. The combination of the radial axle with the single bogie had been peculiarly happy. He had employed the bogie principle exclusively on various large railways, and in some instances in Spain, and he considered that principle of central motion, if he might so express it, which was due to the bogie, had been simplified, and even brought to perfection, by the mode in which the radial axle-box had been so practically and so successfully applied.

Mr. G. H. PHIPPS said, he had not the pleasure of being on the engine when the recent experimental trip was made, but he thought the invention ought to be yet further considered and tested before finally adopting it. When an engine fitted with the radial axle boxes oscillated on a straight line, whatever the amount of motion might be, it would slew the axle round as much as the same amount of 'end on' motion of the axle would do when the engine was working on a curve; he conceived that this slewing of the axle on a portion of the straight line of a railway might be dangerous, and might give the flange of the wheel a tendency to mount upon the rail, particularly if the oscillation happened opposite a bad joint, or other defect on the inner edge of the rail.

He thought very well of the general principle of the radial axle box, and he had for a long time given much attention to the same subject; but he confessed he thought some modification was still required to make it perfect. His idea pointed to something in the nature of a spring, placed at right angles to the axle, and pressing against collars upon it whenever the axle underwent any 'end on' motion; then, if a sudden blow, lasting only for a very short time, were given to the axle, it would simply move 'end on' without slewing; but if the acting cause were constant in its action, as for instance, the pressure of the rail against the flange of the wheel on a curve, then the axle would slew as desired.

He would remark, in reference to the difficulty of regulating the proper elevation of the outer rail, when curves occurred without the intervention between them of a portion of straight line, that Mr. Robert Stephenson had frequently suggested to him, that the raising of the outer rail was not intended merely as a means of meeting the centrifugal force, but also to throw the centre of gravity of the engine nearer to the inner rail. In a curve of 500 feet radius, at 10 miles per hour, the requisite elevation to correspond with the centrifugal force would be 2 inches. It might be worth while to inquire, what the effect would be if the elevation were made as much as 6 inches instead of 2 inches? In such a case, on a base of 4 feet 8½ inches, the centre of gravity of the engine would be thrown over nearly a like quantity of 6 inches towards the inner rail; consequently the outer rail would be relieved of considerable pressure, and the wheel would thus have a better opportunity of going round the curve without much friction. Therefore he threw out the suggestion, whether a greater elevation than was due to the centrifugal force might not be a useful thing.

Mr. VIGNOLES said, with respect to reversed curves, there was no regulation in this country, but on the Continent—in France, Germany, and Spain—there was an established rule, for the purpose of avoiding the grinding action to which reference had been made; it was that there should always be a straight interval of 100 metres

between the termination of one curve and the commencement of another proceeding in an opposite direction. He could not say he assented to the law, which was merely empyrical; he had drawn attention to the fact merely to show, that it was a subject which had not escaped notice in other countries. With respect to the elevation of the outer rail, it was well known that the velocity with which a train passed formed a very material element in determining what should be the amount of that elevation. At the same time, he agreed it was better to give a little extra tilt to the rail to obtain the additional facilities which had been alluded to.

Mr. Scott Russell said, there was one point which he particularly recommended for consideration:—the interposition of a piece of straight line between two reversed curves had been mentioned as having had the sanction of Engineers on the Continent, but it was a clumsy expedient, and not a solution of the difficulty which had been brought forward. He was, however, glad that the law in question had been alluded to as empyrical, and not recommended for adoption. The real fact was, if two reversed curves met, it was generally because there was no possibility of the intervention of a straight piece. He had had experience in the effect of running straight lines into canted curves, and he found that the result of introducing a straight piece into a canted curve without the addition of other precautions, was the creation of the very evil it was intended to avoid, and on passing from a sharp curve to a straight line, the same difficulty occurred.

As an indication of the direction which the researches should take, he would point out that if this question were examined carefully, there would be found a mode of passing from one sharp curve into another of equal flexure, by means of such gradually diminishing curvature, that the wheels both of engines and trains might go round reversed curves without grinding on either rail. He thought it was a pity to bring over-refinement into this question, and the only practical solution he knew of, was slightly to cant the straight line before entering on the curve, and slightly to diminish the cant of the curve before entering the straight line. The next point had been well put; but not quite solved. It was, that for every speed there was a different cant. It appeared to him that the solution of the question was to take the extreme speed for the measure of the cant; and then, probably, in the intermediate speeds would be found exactly the required medium. He recommended the whole of this subject as a field in which the mechanical and the mathematical powers of the younger Members of the Institution could be exercised with advantage.

Mr. G. W. Hemans remarked, that the attempt to equilibrate the motion of a train on a curve by raising the outer rail had already been carried as far as it was considered safe to do it. He

had been obliged to ascertain what could be got out of that mode of equalizing the motion of a train, and he believed no improvement could be found in that direction. He knew instances in which the outer curve had been raised so much, that the inner rail had borne nearly the whole weight of the train, and yet without preventing the flanges grinding upon the inner edge of the outer rail. That elevation had been carried to 6 inches or 7 inches round sharp curves, and with no good result. If any advantage was to be obtained in that respect, it would be from some invention like that of the radial axle-box, which appeared to be one of great merit. At the same time, he concurred in thinking it required to be watched with care, as to its perfect suitability for all speeds, and for going round all curves.

With regard to the permanent way under discussion, he had always had great regard for the ingenuity of the Author of it, and had gone to some expense in trying his inventions, and sometimes when no beneficial result had been apparent. He had tried permanent way on wrought-iron longitudinal sleepers, on cross-sleepers, on flat-footed rails, bridge rails, and rails upon chairs; but he was sorry he could not quite concur in the results finally deduced, as to the system of permanent way then brought before the Institution being the best. The Author considered the best thing would be, the double-headed rail placed on fixed supports or chairs, and that those should be fixed on longitudinal sleepers and be confined by a bridle or stirrup to the longitudinals, and that the longitudinals again should be fastened upon cross-sleepers. That was a kind of permanent way Mr. Hemans had tried to some extent, and he might point out some serious defects in it. The principal one was the great cost, and the necessity of covering the whole of the timber, of unusual thickness, with ballast; for the upper timbers, when left uncovered, decayed so rapidly, through the alternations of wet and dry, and heat and cold, that he was obliged to abandon the system. He thought Mr. Adams had failed to obtain what he wanted, viz., a rigid rail, but an elastic substratum. He believed, if a longitudinal bearing were used, covered by a rail directly secured, so as to obviate the necessity for the intervening chair or other support, there would be elasticity enough for the purposes required. He for one thought it was high time to have something better than the double-headed rail, in a cast-iron chair, nominally fastened with wooden keys and pins which did but little good, and which were frequently held in their places only by the pressure of the ballast round them. He believed the flat-footed rail, on continuous, or even on cross bearers of timber, with a base of not less than 5 inches, and with a good fish joint, was better than the double-headed rail, which ought never to be turned, and which he thought should be dispensed with altogether.

Mr. W. H. Barlow thought the remarks as to the usual mode of constructing a permanent way were rather severe. After many years' experience, that system had been adopted throughout the country; and, although he assented to some of the objections, he thought there were certain advantages connected with the double-headed rail which could not be got in any other way. One advantage was, its perfect symmetry and its tendency to keep straight. That symmetry he regarded as an important condition, because, if a rail in cooling became twisted, no mechanical process could make it straight again. Though concurring as to the merits of the elastic road, he could not admit its claims to novelty; in principle it was almost identical with a portion of the road used on the Manchester and Birmingham Railway in the year 1840, and designed by Mr. Buck, the Engineer of that line. An experiment of having the wheels of a carriage on one side larger than those on the other had been referred to. He had seen that plan tried; and he agreed in what had been said upon it. The normal motion of the carriage was in a perfectly straight line, when the axles were parallel; but when the axles were not parallel, the result in every case was, that the carriage moved round in a curve, the centre of which coincided with the point of intersection of the converging lines of the axles produced.

Mr. George Berkley said, the results of the experiments with the radial engine had been fully stated, and were very satisfactory. The trial of the engine was, however, merely an experiment. Inventions such as that under discussion required much consideration before Engineers could adopt them with confidence. This engine, from its construction (having inside cylinders, and all the parts well balanced), had not much tendency to oscillate. Its steady running, therefore, furnished no sufficient guarantee that engines of this description, with outside cylinders not so well balanced and more worn, would run steadily at great speeds. On curved lines, where the speed would not be great, this construction of engine appeared to present an opportunity of saving the wear and tear of the tires and rails. He thought the invention exceedingly ingenious.

Mr. Gregory, V.P., wished to explain, that the lateral oscillation was not so free as Mr. Phipps supposed, because the weight of the engine being borne directly upon the axle-boxes, by means of sliders, the friction due to that weight had to be overcome before the axles would vibrate so as to lose their parallelism; and owing to the cone of the wheels the weight of the engine tended to keep the axles in their proper position. He might add that he could not agree in one conclusion drawn by Mr. Hemans. He could not understand how, unless there was an undue raising of the outer rail, there could, in the ordinary working of curves, be any

greater amount of weight on the inner rail than on the outer rail. It seemed to him that when trains were running round curves the result of the combined forces of gravity and centrifugal action would be to produce equal weights upon the two rails.

Mr. PHIPPS remarked that he had most distinctly said, when the elevation due to centrifugal force was given, the pressure on the two rails was exactly equal. The suggestion he had offered was to give more elevation than that.

On the subject of spring tires, he thought that, like experiments on ships, it was a most important thing so to manage the experiment as to illustrate, as far as possible, only one fact at a time. This intervention of the spring tire gave the wheels the power of turning round, to some extent, independently of each other, thus acting somewhat similarly to a friction clutch; but suppose such a friction clutch were applied without any spring tire at all, how far would, or would not, the power thus given the wheels of turning independently of each other, favour their motion in going round a curve. Experience showed it would not do to detach the wheels entirely from each other, because then the engine could not be kept square to itself on a straight line.

Owing to the joint effect which the tires under discussion possessed, partly of acting as springs, and partly as friction clutches, he was afraid that no direct conclusion could be come to, as to the proportion of the advantage said to be gained by these tires, which should be assigned to either of the above properties.

Mr. HEMANS was at a loss to understand how, if the centre of gravity was thrown more on one wheel than another, that wheel did not bear more weight; and he would invite attention to the fact, that the inner rail on a curve was generally worn down, while the outer one was comparatively unhurt.

Mr. E. WOODS said, with regard to raising the outer rail of the curve, that no doubt the elevation of the outer above the inner rail was that which, in ordinary circumstances, contributed to neutralize the tangential force. By raising the outer rail, the engine was placed transversely on an inclined plane, and this brought the force of gravity to bear in counteracting the tangential force of the train. In ordinary engines, such as were furnished with axles running in rigid frames, that was the only way of resisting the tangential force. But in another class of engines, in which a special provision was made for accommodating the position of the wheels to the curvature of the road, such as the modification of the truck supporting the front end of the engine, known as the "Bissell truck," a further principle was brought into play. This had been introduced on American railways, and also in Chilé, by himself, and in Spain by Mr. Vignoles. The element brought into operation by this form of truck was the weight of the engine

upon its frame; for instead of the engine resting upon the truck and swivelling upon a fixed pin and plate, it rested upon a moveable plate, or block, which was permitted the power of transverse motion, moving upon two pairs of inclined planes, which inclined upwards, from the centre towards either side, so that when the engine was going round a curve, the body was lifted up on the frame itself, in proportion to the extent of the deviation of the curve from its tangent. By that means the weight of the engine tended to force the wheels into true position, irrespective of the elevation of the outer rail.

Mr. T. E. HARRISON thought the degree of elevation to be given to the outer rail was pretty well understood. It was not merely a question of giving a calculated amount of cant to the rail,—one element was the speed at which the engine travelled,—and he would say, that in cases where it was calculated that it would be necessary to raise the rail to the extent of 6 inches or 7 inches, a speed was implied which no one should adopt round such a curve. He thought, in practice, nothing facilitated the passage of an engine round sharp curves more than giving a little additional width to the gauge of the rails at such parts of the line; and if it were assumed to be necessary for trains to travel at a high speed round sharp curves, then, he thought, it was necessary at once to adopt such a plan as that of the ordinary bogie engine, or that recommended in the Papers. He looked with the highest respect upon everything that came from the Author of that plan; for in all matters of permanent way, a great amount of valuable improvement was due to the constant attention which he, for the last thirty-five years, had given to the subject.

Mr. J. M. HEPPEL was present at the experiments with the radial engine, but the results had already been so well explained, that he had little to add. He would say in all his experience he never rode on an engine which ran at such speed so steadily and so well. With reference to radiating axles, in contradistinction to the ordinary bogie frame, he might remark that in going round a curve there were two desiderata—one was, that the centres between the two wheels should be brought to coincide with the centre line of the curve; and the other, that the axles should be brought into the direction of normals to the curve. The ordinary bogie frame, as usually applied to locomotive engines, attained the latter of these two objects imperfectly, and the former not at all.

In the engine in question, by the proper choice of the centres from which the circular slots in which the axle-boxes slid were struck, a motion was obtained whereby both the objects he had referred to were completely accomplished. The leading axle not only placed itself normal to the curve, but at the same time brought

its middle point truly over the centre line of the rails. He thought it might reasonably be anticipated, that great ease in passing round curves would result from such an arrangement; and he was happy to add testimony to the satisfactory manner in which this expectation had been verified by the experiments he had witnessed.

Mr. HAWKSHAW, Past-President, said, he could not concur in some of the observations which had been made in the course of the discussion. He did not agree in the opinion that it was the same thing to pass from a curve to a straight line, and to pass from one curve to another reversed curve. The angle of motion in the latter case must be greater, and the centre of gravity would have to be shifted double the distance. Neither did he think there was no advantage in giving a cone to the wheels of a locomotive engine. He concurred in the observations based upon the supposition, that the axles were always parallel to each other; but that supposition was not quite accurate. The fact was, the object in giving a cone to the wheels of a locomotive was this; when the engine was driven by centrifugal force on to the outer rail, the wheels ran with a larger diameter on the outer rail and a smaller diameter on the inner rail, and therefore the wheels formed the frustrum of a cone. Of course that could not take place without the parallelism of the axles being disturbed. In fact, there was motion enough in the axle-boxes of all locomotive engines to admit of sufficient motion to change the parallelism of the axles so as to coincide nearly, though not quite accurately, with what was necessary. The moment the wheels formed a frustrum of a cone, the axles had to change their direction, to some extent: therefore there was an advantage in giving a considerable cone to the wheels of locomotives and other vehicles.

He did not agree in the remark that, up to the present time, a good permanent way could not be made, or that the plan had yet to be discovered of making one. He believed any one could make a good permanent way, if sufficient money could be spent upon it. The defects of the permanent way consisted mainly in the fact, that efforts were always being made to form it too economically. Any one of experience could make a much better permanent way if he felt he might incur a greater expenditure, and the defects arose more from the attempt to make and to maintain permanent ways too economically than from any want of knowledge.

With reference to the capacity of engines for passing round curves, he had recently had an opportunity of inspecting the improvements contemplated by Mr. Adams, and of riding upon the engine described in Mr. Cross's Paper, from Bow to Camden Town. It was no doubt important that something should be done to enable locomotive engines to pass round quick curves without those jerks

and jumps which sometimes took place in the ordinary class of engines. That had been done, to a considerable extent, by what was called the bogie; but that plan took up a great deal of room, and, in some cases, interfered with space which could be better applied to other purposes. He thought Mr. Adams' engine possessed many elements of usefulness, which, with a little more care and elaboration, might prove advantageous where locomotive power was applied to pass round quick curves; and, as far as he could at present judge, it did not seem liable to get out of order.

Mr. Wm. Adams said, as Engineer of the North London Railway, he might be expected to give some particulars of the trial in question. He could not say precisely what the speed was, but, as far as he could judge, the down journey was made at the rate of about 50 miles per hour, and the return journey at rather more than 60 miles per hour. That was near the Edgware Road. One object of the high speed was to test Clark's continuous break, which was applied to the train. The engine had been on the North London line for experimental purposes for a week, and he had run several trips with it, going round sharp curves at high speeds to test its steadiness. The engine had gone round a curve of 2 chains radius at Poplar without showing any tendency to mount the rails, but that was at a slow speed. Curves of 20 chains radius had been gone through, at the rate of about 35 miles per hour; but it was contrary to custom to pass curves at high speed. He had lately been to St. Helen's, to test an engine of that kind on the line for which it was designed. He took a coal-train about 7 miles, and on that day some part of the road was in bad order for want of packing; the oscillation of the coal-trucks was remarkable. At a speed of 40 miles it was so excessive that the steam had to be shut off, but the engine was perfectly steady. He had been much surprised by the absence of slipping in the St. Helen's engine, and he thought that absence of slipping was to be accounted for by the spring tires. There was a considerable difference in that respect between the St. Helen's engine and any other.

Mr. Jas. Cross, in reply, said the only point which called for notice was an erroneous impression that the St. Helen's engine had been merely constructed for the purposes of experiment, whereas the fact was, it had been running regularly for six months, and came straight off work to London for the purpose of being exhibited to the Engineers of the Metropolis. Having had the engine under his notice for six months, he believed, however perfect it was in going round curves, it was still more so on straight lines. He knew no engine that ran so steadily on a straight line.

Mr. W. B. Adams said, that the radial engine ought now hardly to be considered an experiment, strictly speaking, because it had

been in use a considerable time; but whatever merit there might be in the engine, he was indebted to Mr. Cross for the opportunity of working out his idea.[1]

In his opinion, the adhesion which had been referred to was attributable to the elastic action of the tire: there was a certain amount of flattening of the tire upon the rail. There was another fact, that the wheel could slip round within the tire, instead of the tire slipping on the rail, which compensated for any unequal diameters in the four coupled wheels, and prevented the grinding which usually took place in coupled wheels. A horizontal rocking action of the tire also took place and prevented the flange from being worn. Flange wear was usually the result of a shearing action, and that could not take place without a rigid bearing against the rail.

With regard to the radiation of the axles, it was evident that the lateral unsteadiness of an engine must be due to the fact, that the flange of the tire was a rigid body which, in impinging upon the rail, caused the engine to sway laterally, and the wheel occasionally to mount the rail. With the wheel so constructed that it could easily get out of the way, the rigid impinging did not take place; for before the flange of the tire came in contact with the rail the cone of the wheels came into action, and the flange was fended off from the rail precisely like the steam-boats at the river piers. He believed that Staffordshire tires, which were those used, would stand double the wear of Krüpp's tires.

As to the portion of the permanent way of the Manchester and Birmingham Line, which had been alluded to, he had no doubt that Mr. Buck was capable of inventing that or any other thing that was required for a railway; but it was quite certain that the idea of the permanent way, which was the subject of the Paper, was not taken from the Manchester and Birmingham Railway. In fact, Mr. Adams had never heard of it. Mr. Buck's plan appeared to have been an experiment for an especial purpose, and never published. Apart from that question, the motive of Mr. Adams for it was this:—Having succeeded in producing from iron tires a greater result than was produced from steel, he argued that the true system for rails was analagous to that for the tire, and that the destruction could only take place by the blow, or friction between the tire and the rail; and he argued, that if he could get elasticity, he should avoid that destruction. At his instance, Mr. Chubb, of the North London Company, caused longi-

[1] The subsequent daily use of the radial engines on the Great Northern, the London, Chatham, and Dover, and other lines, is conclusive as to lengthened experience. It is perfectly practicable for these engines to carry 2,500 gallons of water, adapting them for express trains.—W. B. A.

tudinal sleepers to be fastened on ordinary cross-sleepers, packing the cross sleepers, but not packing the longitudinals. The practical result of this, he thought he might state, had been, that whereas the life of the rails on the North London Line was three years, these rails of the ordinary iron stock had now been down two years and four months, and showed no signs of wear whatever, except a polish on the surface—no blow, no scaling, no indent, except at the junctions, where two end rails were split from being rigidly connected by chairs of the ordinary class. There had been no packing. Those rails had never been opened since the time of laying them down, and that was in wet weather. One cause of the duration appeared to be due to this fact, that whereas, in ordinary rails the pressure came direct upon the rigid body of the rail, without any elastic medium between, in this case there was no rigid part whatever, but one continuous elasticity from end to end. There was no rigid point on which a blow could be struck. Mr. Mathews, the Superintendent of the North London Line, had laid a piece of that line on the Poplar branch, the cross sleepers being overlaid with longitudinals, 11 inches × 4 inches, and with two bracket supports between the cross-sleepers. The quantity of timber used in that way was not more than the ordinary amount, and it appeared to answer very well, and the elasticity appeared to have prevented destruction.[1] The chief difference between steel and iron rails consisted in the fact that steel was homogeneous—there was no grain in it. Iron rails were made of bars of iron, welded in an imperfect manner, and the effects of a blow upon the two materials were very different. In the one case there were fibres, as in a piece of wood, while the other was quite homogeneous. The iron itself was probably harder in texture than the steel rails, and the latter, in some cases, were indented by the chairs more than the iron. In point of duration steel rails would last longer than iron, simply in virtue of being homogeneous, and consequently better able to resist heavy blows. There was the fact that rails which ordinarily wore out in three years had not, after two years and four months, shown any signs of wear; the reason was that, by the elastic yielding the force of blows was diminished more than one

[1] On the 25th of May, 1865, Mr. Matthews, the superintendent of permanent ways, writes thus: "Seven of the 'Sandwich' rails supplied by the Bombay and Baroda Railway Company were laid on the 30th November, 1859, four lengths of which are still in use (5½ years). The elastic way, with sleepers 3 feet apart, was laid in the month of January, 1862 (3 years 4 months), and the piece with the sleepers 6 feet apart was laid in the month of April 1864 (1 year 1 month). This last piece gave some remarkable results in the joints, which were badly fitted brackets, 9 inches long, with only one bolt in each rail, consequently working as loose as an old-fashioned joint chair; but the elasticity had prevented any abrasion of the rail ends."—W. B. A.

half, being distributed over two or more sleepers, instead of being confined to one.[1]

In reply to questions, Mr. Adams stated, that on his system, the chairs were 3 feet apart; that the cross-sleepers were simply a support, like the piers of a bridge, and were best adapted to their purpose when most unyielding. He thought if the supports were perfectly rigid, having elasticity above them, it would be competent to make the whole of the substructure in the same way perfectly rigid, and ordinary ballast might be dispensed with, by substituting surface drainage under the longitudinals and between the cross sleepers. In the case of longitudinal sleepers, and in the ordinary way, no elasticity proper was obtained when put upon ballast, but simply a more elastic yielding, which was due to whatever compression there was in the wood. He had seen rails enter into the timber to the depth of an inch, which could only be accounted for by the yielding of the iron and the compression of the timber. In this case nothing of that action appeared to take place. Mr. Adams did not doubt that, with rigidly fixed cross-sleepers, and in the absence of blows, the ordinary packing might, in almost all cases, be dispensed with. The ballast was laid up level to the longitudinals, but not supporting them, or preventing their elastic action. It was laid on a part of the line over which 120 trains a day passed. He would prefer to have the longitudinals entirely in the free air above the surface. As regarded liability to get out of gauge, his system of permanent way was less liable to that defect than the ordinary road, because no single cross-sleeper could travel laterally without its neighbours.

Mr. Bidder, Past President, said, the time had arrived when the Institution should address itself to the question of locomotive power and economy. A Paper, commencing with the powers and performances of the earliest locomotive engines, dating from those tried in the competitive contest on the Manchester and Liverpool line, and tracing, down to the present time, the power such engines possessed and the economy with which such power was applied, would be of great interest to himself and of real use to the profession. He believed it would elicit a discussion of great animation and value. As far as his own investigations had gone, he had arrived at this conclusion—that the present locomotive engine had nearly four or five times the power of those with which the Manchester and Liverpool Railway was initiated. He

[1] No doubt what are called steel rails will ultimately displace iron rails, being a less costly manufacture and more durable; but if really steel, that is, containing the quantity of carbon constituting steel, they must either be hardened and tempered, or annealed to softness. Steel varying in hardness and softness in rails is a very treacherous material.—W. B. A.

believed that that enormous increase of power was worked, mile for mile, at less than half the cost of the earlier engines, and even taking the date of the opening of the London and Birmingham Railway, the engines now possessed six times the power, and were working at less than half the cost of the engines of that period. He could not help thinking this was a subject more particularly belonging to this Institution and one which ought to be thoroughly investigated and exhausted: and he hoped that on the list of premiums next year, the subject of the gradual extension of the powers of the locomotive—the improvements which had been carried on from year to year, and which were still in progress, would be included. At all events, a record of that kind ought to be placed in the archives of the Institution, and he was sure its resources could not be better applied than by inviting a Paper on such a subject. He was glad the subject had been opened by the Papers last read. He had not inspected the radial engine himself, but he had received a very favourable report of it.

May 3, 1864.

JOHN FOWLER, Vice-President,
in the Chair.

The following Candidates were balloted for, and duly elected:—WILLIAM CROSS BUCHANAN, GEORGE EDWARD GAVEY, and JAMES MAY, as Members; ROBERT HANNAY, RICHARD LANGRISHE, FREDERICK LESLIE, THOMAS RICHARDSON, Ph.D., and ARTHUR SAUNDERS, as Associates.

The discussion upon the Papers, No. 1,113, "On Locomotive Engines for ascending Steep Inclines," and No. 1,117, "On Friction between Wheel Tires and Rails," was continued throughout the meeting, to the exclusion of any other subject.

May 10, 1864.

JOHN ROBINSON M'CLEAN, President,
in the Chair.

No. 1,112.—"On the Distillation of Coal, the Utilization of the Resulting Products, and the Manufacture of Coke." By M. PERNOLET, of Paris.

BY what means the products of the distillation of coal may be utilized, and the price of coke reduced, are questions which have long engaged the attention of economists and of men of science. But the Author believes, that, on the Continent, by recent improvements in the method of charring, and in the arrangement of the ovens, these questions have been at last practically solved. Of these improvements, as well as of the best processes now in use for the manufacture of coke, a description will be given in this Paper.

In the improved system, the method of charring is founded, principally, on the theory of keeping the coal from all contact with the atmosphere during its distillation, of performing that process very slowly, and of collecting and turning to account all its products, while the coke shall retain all the solidity, lustre, and density which are its distinguishing characteristics, when manufactured in the best manner by the ordinary means. It is a system which has been sanctioned by abundant experience, both in Belgium and in France, where it is actively pursued at ten different establishments, employing more than four hundred ovens of the largest dimensions, each capable of receiving from 5 tons to 7 tons of coal at one charge; and it possesses the important additional recommendation, of realizing all the above advantages, simply by the aid of some inexpensive modifications in the ovens at present in general use, especially in England, where the form of the roof is hemispherically vaulted. In fact, one peculiar merit in these improvements, deserving the careful attention of Engineers and manufacturers is, that the economy both of the apparatus and working is so great, that the value of the supplementary products obtained in the first year is sufficient to cover, more than three times, the expense incurred in altering the ordinary furnaces.

Before entering into a detailed description of the apparatus, and in order that a just estimate may be formed of the reduction in the price of coke which must result from its employment, it will be necessary to state, that the supplementary products due to the im-

proved arrangements are, a larger yield of coke, and all the tar, the ammoniacal liquors, and the gas, which would be obtained from the same coals, if distilled in the retorts of a gas manufactory.

The increase in the yield of coke depends partly on the kind of coal, and partly on the way in which the charring was done before the introduction of the improvements. In the great coke works at St. Etienne, where ovens with hemispherically vaulted tops are used, the yield of coke has been advanced from 58·8 per cent. to 69·3 per cent., and in the 'Fonderies et Forges d'Alais,' from 54·6 per cent. to 69·5 per cent. In general, it may be said, that the increase in the yield, from the rich and partially rich coals, is from 10 per cent. to 15 per cent. Consequently, in distilling the same quantity of these coals, there will be a return of coke exceeding by one-sixth, on an average, that which was obtained from the old ovens before their alteration. As to the tar, the proportion collected depends on the nature of the coal, and on the care taken, both in the distillation of the coal, and in the condensation of its volatile products. This proportion has averaged upwards of 2·53 per cent. at the 'Forges d'Alais,' 3 per cent. at Elonges, 3·25 per cent. at St. Etienne, and has reached as high as 5 per cent. from the ovens of the Paris Gas Lighting Company, where only very bituminous coals are employed. Taking, therefore, the average of these manufactories, the amount of tar obtained from the bulk of coal distilled may be reckoned at 3 per cent. The proportion of ammoniacal liquors depends, not only on the conditions mentioned for the coke and tar, but also on the quantity of moisture contained in the coal. At the works of the Paris Gas Lighting Company, where unwashed coal is used, for every 100 parts of coal distilled, there is not obtained much more than 6 parts of ammoniacal liquors; while at Elonges, at Produits, and at St. Etienne, where the distillation is principally from washed coal, the quantity of liquor collected amounts to 10 per cent. or 12 per cent. But in other respects, the useful substances contained do not appear to have any relation to the amount of water collected; and the aggregate of resulting ammoniacal substances shows but little variation for the different coals which have hitherto been tried. Provided the condensation be properly attended to, this quantity may be stated at a weight of not less than 10 lbs., and sometimes of as much as 13 lbs., of sulphate of ammonia per ton of coal distilled.

The gas obtained has not been computed at any ovens except those of the Paris Gas Lighting Company. There it is found, that, by charging the ovens to a height of 2 feet 4 inches, and distilling 6 tons per oven in 72 hours, from 10,000 cubic feet to 11,500 cubic feet of purified gas are generally obtained from a ton of coal, yielding from 69 per cent. to 70 per cent. of coke, fit for delivery to the railway companies. The density of this gas, is to

that of common air, as 40 to 100; and its illuminating power is equal to that obtained from the same coals distilled in retorts, in the ordinary manner of gas manufactories. So that, the weight of purified gas is about 15 per cent. or 16 per cent. of the coal distilled.

Where coke is manufactured for metallurgical purposes, as at Elonges, at Produits, at St. Etienne, and at Alais, it is not usual to collect the gas given off, but it is conducted beneath the ovens, to be there consumed, in maintaining the necessary temperature for distillation. Provided that the coal is rich, as at St. Etienne, or partially rich, as at Alais, this gas will be found sufficient for the purpose (precaution being taken to avoid the risk of explosion); but, generally, it is desirable to force the heat, in order to obtain at once a firmer coke and a tar richer in benzine. This is effected without any increased expense, by burning in addition, in the fire-grate, either the small rubbish which is not good enough to be sold as coke (and which, at St. Etienne, forms from $2\frac{1}{2}$ per cent. to 3 per cent. of the weight of coal distilled), or the residue from the washing, which is of equally small value, and amounts, at Produits, to about 10 per cent. of the volume of coal distilled.

At Paris, where the heating of the ovens is entirely performed with gas-coke from the retorts, from 22 per cent. to 23 per cent. of the weight of coal distilled is burnt; but as this coke contains, probably, not less than 12 per cent. or 15 per cent. of cinder, the consumption stated, represents about 20 per cent. of pure coke, that is to say of carbon. This statement will give an accurate idea of the maximum amount of heat required for the ovens still in use by the Paris Company, which are large and cylindrically vaulted, 23 feet 4 inches long, by 6 feet 8 inches wide, and are provided, at both ends, with openings, the full size of the furnace, closed with cast-iron doors; this arrangement, however, is not the most advantageous, and is avoided in the ovens of the 'Société de Carbonization.'

It follows, that by the improvements in the manufacture of coke, there can be extracted from 1,000 tons of pit coal:—1st, from 650 tons to 700 tons of good coke, instead of the 500 tons, or 600 tons generally obtained in England; 2nd, from 25 tons to 40 tons of tar; 3rd, compounds of ammonia, equivalent to, at least, 5 tons of sulphate of ammonia.

Therefore at the actual prices of these different products, in those parts of the United Kingdom where they are lowest, viz., 7 shillings, or 8 shillings per ton for the coke; from 20 shillings to 30 shillings per ton for the tar; and £14 or £15 per ton for the sulphate of ammonia, the total net value of the supplementary products which the improved ovens extract from 1,000 tons of coal, is more than £100, or about 2*s.* 3*d.* per ton.

If it be considered that, at Newcastle and Wigan, in order to procure one ton of coke, worth about 8 shillings, it is not at all uncommon to use 2 tons of rich coal, and, that the nature of this coal is such as to permit of the extraction of all the supplementary products, it will be seen, that the adoption of these ovens would effect a saving of more than 4*s.* per ton of coke manufactured, and consequently would reduce its price more than 50 per cent.

This reduction might be carried still further, if all the gas, or even part of it, were made use of, as there is every facility for doing, particularly in those metal works which have both coke ovens and gas apparatus, and also in those small gas factories where cannel coal is generally used. The latter item of expense might be entirely got rid of by the alteration of some of the ordinary ovens, for the employment of the gas would effect so great an economy, as to constitute an advantage, equal or even superior to that which could be obtained from the supplementary products estimated at higher values. Because since, on the one hand, the gas produced by the improved ovens is capable of supplying all the heat required for the distillation of the coal, and, on the other hand, this heat can be produced by 20 parts of carbon to 100 parts of coal distilled, it follows that the process of heating would not consume more than 500 lbs. of the most ordinary coal, to transform into coke a ton of coal, yielding, in these ovens, from 10,000 cubic feet to 11,500 cubic feet of gas, at an average expense of 1*s.* at the highest, or at about one penny per 1,000 cubic feet, or at less than the thirty-sixth part of the lowest price of gas employed in Newcastle, for the town supply.

The reduction in the price of coke, effected by the use of the improved ovens, will generally be, at least, from 4*s.* per ton to 4*s.* 6*d.* per ton, and it may amount to 8 shillings or 9 shillings per ton. But it is important to make a more profitable use of the gas, than that to which it is applied in most of the establishments referred to; for it is frequently burnt, when the most ordinary description of fuel would afford all the heat required, and when this large supply of gas might be greatly increased in value by reserving it for special purposes, not limited to the lighting of towns, but extended to heating steam boilers, or stoves, or the air of blast furnaces, or to evaporating and distilling liquids, puddling cast iron, reducing mineral oxides, and to many other uses, of which some have yet to be and no doubt will be discovered. On this point, it may be remarked, that M. Berthelot has proved, that one of the elements of illuminating gas may be transformed into alcohol, and that hitherto this manufacture has only been stopped, by the expense of evaporating the dilute sulphuric acid, which is present in large quantities. The gas of the improved ovens being able to furnish, at once, both a source of alcohol at a

low price, and a fuel eminently fitted to evaporate it, may, perhaps, help to introduce this manufacture into the field of commerce.

As regards the use of gas in blast furnaces for the manufacture of cast iron, an application of it by the 'Cie. des Forges de Franche Comté' has been recently made, by which, it is said, a purer iron has been obtained, with a saving of 40 per cent. of the fuel usually necessary; and it is also stated, that, after several weeks' experience, twenty improved ovens, yielding on an average 20 tons of coke per diem, would keep one blast furnace supplied both with coke and gas.

In the foregoing remarks the employment of the richer, more bituminous sorts of coal, has been implied, and these are, in fact, the best adapted for obtaining the products of distillation. But, though the saving would not be so considerable, the improved ovens may be profitably used for the poorer coals, and even for the anthracites, provided that some of the richer kinds be used with them, as is done at the 'Forges du Creuzot.' In such cases, the economy would consist chiefly in the smaller quantity of the superior coal required, but of course, the products would be proportionately less abundant, in consequence of the small amount of tar, hydrate of ammonia, or gas furnished by the poorer part of the mixture. There would, however, result an important reduction in the price of coke, not only on account of the saving effected in the distillation of the rich coal, but because the poorer kinds, when thus mixed with the richer, instead of being charred alone, would yield three times as much coke as when used singly; in fact by means of this mixture, it is easy to transform into good coke, such coals as are usually considered incapable of being charred, or, at least, of yielding coke in pieces of an available size.

Thus, at Stoke, in Staffordshire, at the works of the Shelton Bar Iron Company, two sorts of coal are used; one flaring, but poor, which has hitherto only been charred in the open air and in large pieces, and the other, partially rich, which is charred in the ordinary ovens,—all the poor, and comparatively small coal (in pieces less than 6 inches thick) being rejected. Yet, by mixing it with the partially rich kind found in that neighbourhood, and by charring the whole in the improved ovens, the poorer coal might be used with facility, and at least 65 per cent. of good coke would be obtained, instead of the 45 per cent. or 50 per cent. produced by the rich coal, when charred by itself in the ovens in actual use.

In certain cases, also, tar, or dry pitch may be used with coals which have little or no bitumen, and which are, at the same time, too brittle to be put into blast furnaces in their crude state. By the admixture of from 8 per cent. to 10 per cent. of the above substances, these coals would be supplied with all the bitumen in which they are naturally deficient, and would then become profitable for

use in blast furnaces; for, if only the small, cheap coal were consumed, the cost of the mixture would not exceed the value of ordinary coking coal. Still, the agglomerating matters, being much more expensive than the small coal with which they are combined, it is always important to economize them; and the best way of economizing them is to exclude the air, and thus prevent them from burning, and to collect the products of distillation, and to contribute to their formation during the process. These recommendations constitute the leading characteristics of the new system.

Description of the Improved Coke-oven.

The alterations consist:—1st. In raising the floor about a foot, and so arranging it that it can be heated from below by means of a fire-grate and flues; 2nd. In making a new opening in the roof, in which is fixed a pipe for the reception and conveyance of the volatile products; 3rd. In so arranging the openings of the old ovens that they can, by means of movable plates of metal and clay, be hermetically closed during the distillation; and 4th. In the addition of a chimney to the masonry, for the purpose of securing the circulation of the products.

In Plate 9, Fig. 1, the coke-oven most in use in England is shown unaltered; and in Figs. 2 and 3 the same oven is represented as altered with the above improvements. S S S is the floor, raised about a foot; underneath it is the fire-grate F, provided with flues A A and A″. I is the opening in the roof. T is the pipe intended to receive the volatile products. P and C are the two usual openings. Fig. 2 shows the same openings, with the addition of the movable plates.

Figs. 2 and 4 show the chimney added to the masonry, X and Y. The dimensions of this chimney, as ascertained by experience, should be 50 feet in height, and the inside area should be not less than $3\frac{1}{2}$ feet square, for a group of sixteen ovens. The sectional area of the main flue should not be less than three fourths of that of the chimney. The oven is represented as arranged for being charged from above, by means of wagons running upon rails, R R, Fig. 2. This plan is the most convenient and the most expeditious. The wagons are brought up in succession over the opening C′, and are then emptied into a movable iron funnel, which must be large enough to receive the whole charge at once; and as the coal falls on the floor, a workman, stationed at P, spreads it equally. In this way, a charge of more than 5 tons can be introduced in fifteen minutes, or twenty minutes, a most desirable rapidity to preserve the heat of the oven when the charge is being renewed. Should it, however, not be deemed

advisable to arrange the ovens for receiving the coal in this manner, the coal may be conveyed through the door, P, in the way most usual in England; but the latter mode is not only slower, but more fatiguing to the workman, on account of the greater height of the floor.

When the charge has been equally distributed, the door is closed, fastened with a screw,' and closely luted with loam; and, until the coking is nearly completed, no further attention is required, beyond seeing that the joints allow neither the air to enter, nor the gas to escape, and that the heat is sufficient, and is equally distributed over every part of the floor. The first of these objects is effected by the simple re-application of loam, wherever there are signs of its being wanted; the second, by the maintenance of a due supply of gas to the fire, through the blast pipe, and by a free draught of air through the centre pipe, or round the edge of the blast pipe, and by a proper distribution of the flames in the flues.

To try whether the distillation is finished, the valve O, Fig. 2, is closed; the communication between the pipes T and T' being thus intercepted, if the charring is incomplete, the gas which is still given off, not having the means of escape, strains the joints of the apertures, cracks the surrounding luting, and, by escaping in the form of smoke, proves the necessity of continuing the process. In this case, the valve is merely reopened, and the gas again passes off by the outlet pipe. If, on the other hand, upon the closing of the valve, there is no escape of gas, the aperture, C, is opened, and a temporary fire-brick wall, separating the charge from the door of the oven, is taken down. It is important not to open the door before cutting off the communication between the pipes T and T', otherwise the external air would get into the pipe T', and become mixed with the gases which are circulating there as they proceed from the other ovens. This arrangement is more fully shown at T' T' T' T', Fig. 4. The door once open, the coke is removed with a rake, or shovel in the ordinary manner. While this is being done, the cast-iron cover at C' is kept shut, to avoid the risk of igniting the coke, by the draft of air which it would create if open.

When the charge has been completely withdrawn, and the cover opened, the oven is recharged. Both at this time, and while the coke is being withdrawn, the gas brought from the other ovens, by the great common flue, and collected by the small common flue, M M M, Figs. 2, 3, and 4, is allowed to pass continually into the fireplace; so that the floor is kept hot, and the gas begins to show itself above the opening only a few minutes after the closing of the door. The covering is immediately put on and luted, and the communication is reopened between the interior of the oven and the great common flue, by raising the valve.

Should it appear that, one side of the oven is insufficiently heated

and the other too much, the registers K K, must be advanced, or withdrawn by means of a hook; or if the supply of gas is too small, the cock Z, Fig. 3, must be opened rather more.

The products of the distillation are drawn off by the draught of the chimney, together with the condensation of the liquid, and the cooling of the gaseous products tends to create a vacuum, which assists the current in the direction shown by the arrows, Fig. 4. The products circulate thus in the great general flue, penetrate into the condensing apparatus Q, Q, Q, Fig. 4 (where they deposit most of the tar and ammoniacal liquor), and return to the ovens by the small general flue, whence the gas, purified and dried, passes to each fire by the pipe H H, Figs. 2 and 3.

The chief uses of the fire-grate are to heat the ovens, when they are set to work afresh, and to raise the temperature of an oven which is not so hot as the others. In this case, the small, unmarketable coke, unavoidably made with the larger, is found to be a sufficiently good fuel. Lastly, in the event of part or the whole of the gas being utilized elsewhere, the fire-grate will be indispensable, for receiving whatever fuel is to be burnt as a substitute.

The products of the distillation pass through the passages marked by the arrows, and rise to the gallery, whence they escape into the atmosphere. The time occupied in charring varies, with the arrangement of the oven, the nature of the coal, and the density desired for the coke. At St. Etienne, it is upwards of 72 hours, for rich coal, but the ovens there used differ from that which has just been described, the form of the vaulting being more elliptical. At the foundry of Torteron, where the rather poor, but very flaring coals of Commentry are used, and where the system of the 'Societé de Carbonization' has been applied to the Belgian ovens, the time occupied is only 24 hours.

The condensing apparatus may be modified according to circumstances. The plan to be adopted will depend upon whether the water supply is scarce, or plentiful. With an abundance of water, the cooling surfaces, and consequently also the cost for iron work, may be diminished.

The cost of altering an oven can be estimated from the elements already afforded in the foregoing statements and in the drawing. The following is a calculation of the expenses actually incurred at St. Etienne. For each oven altered, there were used

	£.	s.
About 6 tons of fire-bricks	3	0
„ 2½ „ cast iron, in different shapes . .	12	10
Common iron, bricks, labour, &c.	4	10
Total	20	0

Exclusive of the value of the gas, the supplementary products gained represent a value of more than 2*s.* 3*d.* per ton of pit coal distilled; and if it be considered, that in an oven of the size of that on which the above calculation is based, not less than 500 tons are charred yearly, it will be seen that only four months' work would be required to refund the expenses incurred, since a profit of £60 per annum upon each furnace would accrue from the more perfect results expected by these inexpensive but most important improvements in the system and apparatus.

The Paper is illustrated by a drawing from which Plate 9 has been compiled.

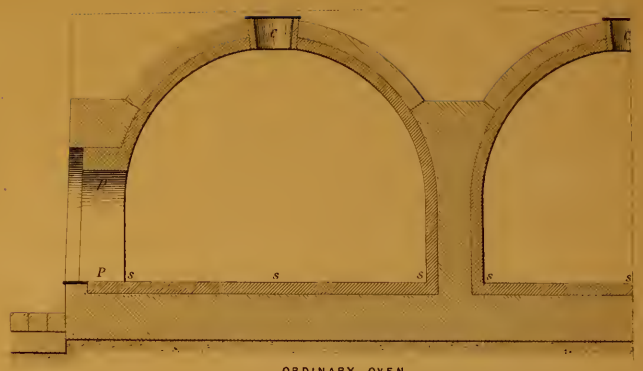
Mr. C. W. SIEMENS said he had lately paid considerable attention to the subject of coke-making; and he believed that the coke ovens generally used, especially in the north of England, were very primitive. The admission of air into them caused a portion of the coke to burn, and the gases from the remaining coal, being driven out, went to waste. He thought it hardly possible to conceive anything more rude than that system, because those gases, possessing heating powers of nearly equal value to the remaining coke, were allowed to escape freely into the atmosphere, involving not only a great loss of fuel in its most valuable form, but also a serious nuisance in populous districts. As regarded the quality of the coke produced in the ordinary oven, it had been satisfactorily proved to be inferior to that produced in the close oven when properly arranged, although it was, perhaps more lustrous in appearance. The reason of its real inferiority was, that the coke first acted upon by atmospheric air was partially burned; but the carbonic acid formed by this combustion passed through the remaining mass in the oven, and robbed it of such an amount of carbon as was necessary to reduce the carbonic acid to carbonic oxide. Hence the earthy constituent of the coke was relatively increased, and, as was stated in the Paper, the coke produced in close ovens contained, for the same amount of earthy matter present, 15 per cent. more pure carbon. This, with a poor description of coal, was a most important feature, irrespective of the value of the additional yield, both of coke and of the secondary products.

As regarded the conversion of the ordinary coke oven into a close oven—which he understood to be the subject of this Paper—he considered that it was practicable, and that the kind of oven now brought before the notice of the Institution had many excellent qualities, but, that it was not the only one possessing important improvements. The plan had been tried, indeed, at Lambeth, with this difference, that coal was burnt to effect the carbonization, the gases being used for illuminating purposes. Those ovens were being pulled down, because the gas produced in them was found to be deficient in brilliancy. Those most in use on the Continent were of two different descriptions. The first was a semi-cylindrical horizontal oven, closed at the ends with movable doors, and provided with a covering arch forming an annular chamber, through which the gases generated in the oven circulated, and were consumed there by the admission of atmospheric air, in order to continue the distillation of the coal inside. That was an improvement, inasmuch as the gases did not go to waste; and he believed ovens of that description were used at the Ebbw Vale works, with great effect. In South Wales excellent coke was

Fig 2.

OVEN OF THE "SOCIÈTE DE CARBONISATION."

Fig 1.



ORDINARY OVEN.

Fig. 3.

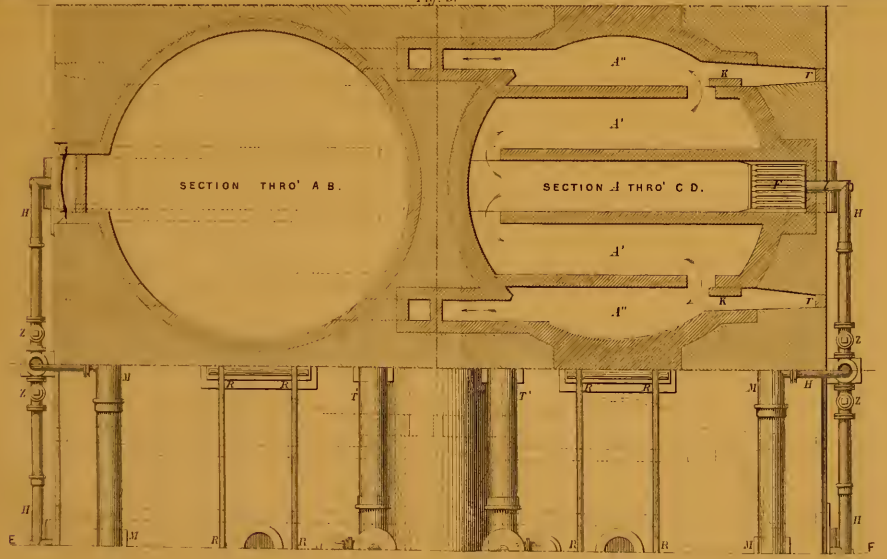
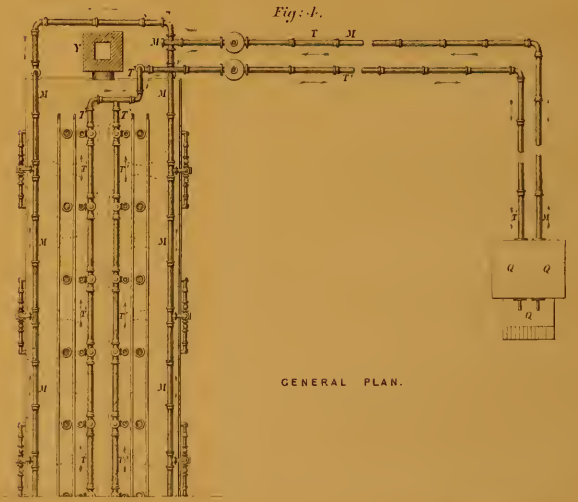


Fig. 4.



GENERAL PLAN.

formed by mixing anthracite with bituminous substances, and by exposing the mixture to great heat in close ovens.

Another description of coke oven which he had seen in France, and which seemed to be a favourite in many establishments, was in the form of a number of upright retorts, and was known as the 'Four Appold.' Each retort was slightly conical, and was filled by shooting the coal from carts at the top. The gases evolved, passed through the sides of the retort, and were burnt there by the admission of atmospheric air. After a distillation of 24 hours or 40 hours, a trap-door at the bottom was opened, and the whole of the coke, amounting to several tons, was dropped into railway trucks, or carts, and carried away. That was another instance where the full value of the carbonaceous material was obtained. He might mention also an oven he had lately tried, which was based upon the same principle, as regarded the general arrangement. It was an upright retort, but, instead of being simply heated by the gas issuing from the coal, a poorer kind of gas was used, which had been previously heated by passing through a regenerator; the air necessary to combustion being also passed through a regenerator placed at the side of the retorts, so that only a portion of the gases evolved was required to heat the coal, the rest being applied to other uses, either for illuminating purposes or for the heating of working furnaces, &c. He had noticed the remarkable fact, that when the gas was drawn from the bottom of the retort, instead of from the top, a much higher illuminating power was obtained. Operating on Staffordshire coal, which, in the ordinary way, yielded gas of about 10-candle power, he had obtained, by this method, an illuminating power of eighteen candles, or twenty candles. Very little tar, or other secondary products were formed, because, in passing over the heated surfaces, they were decomposed and turned into gas, or combined with the coke, which latter was thereby increased in hardness. It might be considered a drawback that there were no secondary products, but it was in reality not so; for in most places the tar and ammoniacal liquor were difficult to dispose of, and if used to improve the coke they were applied to the best advantage.

He thought the question of coke-making had been treated too lightly. The present tendency of engineers was to burn coal in locomotive engines, because coking, as generally performed, was a wasteful process, in which the most valuable part of the fuel was lost. But by improving the coke ovens, and by making judicious use of the gases, both for illuminating and heating purposes, coke might be produced at a reduced rate, to be used for locomotive engines and blast furnaces, and a larger aggregate saving of coal might be effected.

Mr. E. A. Cowper said, that a set of twelve ovens, on the plan of Mr. Henry Eaton, of Bordeaux, were in use at the iron-works of Messrs. Cochrane and Co., Woodside, Dudley,[1] where good solid coke was being made, partly from bituminous coal and partly from Staffordshire coal, and, in some cases, from dry coal, or slack, with an admixture of tar or pitch. The yield had been increased 9 per cent., and, at the same time, the quality of the coke had been improved. These ovens, which deserved to be better known, were arranged in the form of a circle, with rather thin divisional walls between them. While ovens Nos. 1 and 3 were being heated, No. 2 was charged with coal, so that the heat in Nos. 1 and 3 assisted in giving heat to No. 2; and while Nos. 2 and 4 were working, No. 3 was charged, so that the heat of the alternate ovens was of great benefit in working the contiguous, or intermediate charges. The quantity of air admitted through the door was exceedingly small, and, by means of the central chimney, the amount of draught in each oven was equal, and was more exactly regulated than when the ovens were built in a long row. From 50 per cent. to 53 per cent. of coke was produced when common Staffordshire slack was used, in the proportion of 75 per cent. of slack to 25 per cent. of pitch. Of course, there was a certain amount of coke burnt; and in this case, as in ordinary coke ovens, the gases were allowed to go to waste. When 45 per cent. of slack and 55 per cent. of bituminous Welsh slack were used, the yield was from 55 per cent. to 60 per cent. of coke.

He thought, that the old plan of coking in ovens was a crude and wasteful system, and, that it had its origin in the fact, that there was then a demand for the coke, and not for the gas. The coke was therefore made, in the first instance, in heaps in the open air, and afterwards, in order to save it, in close ovens; but still the gas was allowed to pass away, almost entirely to waste. There was no doubt, that gas of illuminating quality could be obtained from coke ovens. Some peculiarly constructed ovens had been tried at the London Gas Company's works at Lambeth; but, after they had been worked about three years, it was found that the gas had not sufficient illuminating power. But if close ovens were made, and if the gas were taken from the lower part, he thought the Company might use it with great advantage. He had had an opportunity of experimenting practically with one of Mr. Siemens's coke ovens constructed on this plan, and had obtained gas of 17-candle power from Staffordshire coal, which would not make gas of more than 8-candle power, or 9-candle power in an ordinary retort.

Dr. Crace Calvert said he had, for several years, paid great

[1] *Vide* "Institution of Mechanical Engineers. Proceedings." 1861. Page 72.

attention to this subject, with some idea of engaging in the manufacture of coke, and with this view, he had visited the Continent, for the purpose of studying the best processes in use there. The result of his inquiries had satisfied him, that the principle of saving the ammoniacal liquors and their products, had been understood and carried out for a considerable period, in Belgium as well as in England. Circular ovens, on Mr. Powell's system, and similar to those described in the Paper, had likewise been long in use, and might be seen at work on a large scale in Durham, in Cumberland, and at Vauxhall, where they had been employed for about fourteen years. In Mr. Powell's ovens the gases could either be reserved for illuminating purposes, as was done in Paris, or be burnt in distilling the coal, as it was in other parts of France and in Belgium, where the same system was pursued. There was not any novelty in the principle of distilling coal in one circular oven, by burning the gas generated in another. The question was, consequently, limited to the relative advantages of circular ovens and long ovens; and, from his experience of what he had seen at Lyons, he might state, that the coke made in circular ovens was rather better than that made in long ovens, because the heat was radiated equally, from the centre to every part, and gave uniformity of quality to the mass, and as the coking was better, the yield was increased by a slight percentage; but there was no increase of gas, or tar, or ammoniacal liquors.

Mr. LAMBERT remarked, that there was not much novelty in the system described in the Paper. Ovens, similar to those recommended, were in use, at the Vauxhall Gasworks, about twelve years since. The coke made in them was exceedingly good, as regarded strength, and no difficulty was found in selling the whole of it, during the three years that method was pursued. Iron founders were anxious to purchase the coke, owing to its freedom from sulphur. He believed that the Brighton Railway Company were supplied with it for six months, and that they discontinued its use chiefly on account of its splitting into small pieces, and falling through the fire bars: that was its only fault.

Mr. JABEZ CHURCH observed, that the most important question was, the method of making the best coke, and whether, by making it in close ovens, it would be of such a quality as was necessary for locomotive purposes. He thought, from his own experience, that it would not; as when made in that way it was inferior in colour, density, and soundness to the coke which was made in open ovens. With reference to the produce, coke made under the best circumstances would yield 70 per cent. upon the quantity of coal used; but its quality could only be tested by ascertaining its heating powers and its freedom from sulphur. He believed, that when made by this process it was more friable, contained a larger amount of sul-

phur, and the heating powers were below that made in ordinary coke ovens. The heating power of pure carbon was represented by the number 340, as 10 grains of pure carbon produced 340 grains of lead by burning it with oxygen from litharge. The maximum heating power of the best charcoal made in this country was about 304, and the heating power of the best description of Newcastle coking coal was 309. The coke made in the gas-making ovens at Vauxhall, though of inferior quality as oven coke, was better than ordinary retort coke; but with the best coals used under these circumstances, he believed it was impossible to make coke of the same heating power as by the ordinary process of combustion. The great feature in coke making was to obtain complete carbonization of the coal, and to prevent a second combustion after it was so carbonized. The atmosphere had a great effect upon it. By cooling the coke down, before it was drawn from the oven, a large quantity of sulphur was passed off, and the quality was greatly improved. If the second combustion were prevented, there was no difficulty whatever in obtaining, in properly constructed ovens, 70 per cent. of coke of superior quality, from the quantity of coal used.

Mr. PENNY said he had had an experience of twenty years in coke making, and though he had not achieved the result just stated, of 70 per cent., yet he had got considerably beyond 55 per cent. or 60 per cent.; but he thought this question should be looked at in another point of view. Coke making was a separate occupation from tar and sulphate making, and, in most cases, it was inexpedient to combine the two. The premises would require to be enlarged, in order to receive the large and numerous condensers necessitated by the increased number of ovens, and if gas-making were embarked in, holders must be added. His experience of coke making was, that the utilizing of the products injuriously affected the quality of the coke. It became of a friable character, for which there was no demand. There was a demand for coke for certain purposes, and it must be produced of the quality required. Where there was plenty of space and blast furnaces to be acted upon, it was quite possible to utilize the products in the way described, as the coke might be used in the furnaces; but generally, in the large manufactories, such as those in the north of England, where the refuse coal was worked up, it would not answer to do so; and, although the mode of making coke in those places, was in itself bad, yet, for the purpose for which it was intended, it was suitable. He might add that, as a practical maker of gas, as well as of coke, he had been surprised to hear, that 11,500 cubic feet of gas could be obtained from a ton of coal under the process described. But the gas so obtained could not have been of the standard quality of commerce, as, under the most favourable

circumstances, and with the best coals for coking, only about 9,500 cubic feet, or 10,000 cubic feet of gas could be extracted from a ton of coal.

Mr. H. P. STEPHENSON agreed with Mr. Church, that coke could not be produced of as good a quality in close ovens as in those which were partially open. As a gas maker, he had carbonized coal in close ovens, and he had found, that the coke was neither so good, nor (which was an important point when it was required for locomotive purposes) was it so large, as that generally used for engines. But if the coke were really improved by the process under discussion, the gas must be proportionately inferior in illuminating power, especially towards the end of the charge, at which period, it would be laden with other matters, involving extra purification. As regarded the cost of labour under the new system, he would remark that, with longer charges, the expense would be greatly increased. In the London works, the most satisfactory results, both as to labour and purification, were obtained from charges of four hours, or six hours.

M. PERNOLET said, the main points which he should notice were, that Mr. Crace Calvert and Mr. Lambert appeared to contest the novelty of the system, whilst Mr. Jabez Church, Mr. Penny, and Mr. H. P. Stephenson expressed doubts as to the advantages it presented, in consequence, as they stated from personal knowledge, of the coke manufactured in close ovens being always friable and sulphurous.

Now M. Pernolet contended that these opinions were refuted by facts which were generally accepted, and were especially well known at St. Etienne (France), and at Elonges (Belgium). These facts were :—1st., that the ovens built on the Powell system at Durham, and at the Vauxhall Gasworks (London), had been so much modified and simplified, that the cost of building had been reduced to one-third or one-fourth of the original expense, which was with justice considered a *sine quâ non* for the introduction of the system for metallurgical purposes; and not only was there now this economy of construction, but care had been taken to design the plans with a view to altering existing coke-ovens at a comparatively small expense: this had been tested and proved by the recent alteration of one hundred circular ovens at St. Etienne, from which very successful results had been obtained; and, 2ndly, that by this system, it had-been found possible to produce coke as large and of as good quality as in the ovens specially adapted for that manufacture only, and still to obtain and use all the gas, the tar, and the ammoniacal liquor. The price at which this coke was purchased for the railways and the blast furnaces proved that the quality was considered as good as ordinary coke.

He must, therefore, contend that the novelty of arrangement,

and the advantages of the system, were fully proved; and, moreover, he felt assured that if the system was generally adopted, there would result an entire absence of the injurious effects upon the trees and upon the vegetation generally which he had observed in the neighbourhood of existing coke ovens in England. He begged to express his thanks to the members for the attention they had given to the question, which he trusted would be practically tested on a large scale in this country.

In pursuance of the notice on the card of the Meetings, it was proposed and resolved unanimously :—

"That in order to insure a fuller attendance of Members than could be obtained on Whit-Tuesday, the Meeting be adjourned until Tuesday evening, the 24th of May."

May 24, 1864.

JOHN ROBINSON M'CLEAN, President,
in the Chair.

The following Candidates were balloted for and duly elected:—CHARLES LENNOX DAVIES, HENRY JAMES WALTON NEVILLE, and THOMAS DYNE STEEL, as Members; JOHN ARTHUR CAPEL BRANFILL, WELLS HOOD, JEREMIAH JOWETT, and ALFRED WILLIAM MABERLY as Associates.

No. 1,120.—"On the Machinery employed in sinking Artesian Wells on the Continent." By GEORGE ROWDON BURNELL, F.G.S., &c.

THE extraordinary depth of some borings, lately made for the purpose of obtaining an Artesian supply of water, has required great skill and contrivance on the part of those who were responsible for the correctness of the processes employed for their execution, and has rendered it necessary to invent special machinery to facilitate the working of the excavations; and, while the principles which are considered to regulate the supply of water to these wells remain unaltered, the modifications of the machinery, thus introduced, have effected such considerable changes in the manner in which the art of well-boring is now carried on, that it becomes Engineers to inquire into the merits of the different systems from time to time pursued. The Author, therefore, trusts that the following description of those systems, and of the several machines in use, may be not uninteresting to the Institution, and may be the means of inducing some Members, in the course of the ensuing discussion, to add the results of their experience to the general stock of knowledge on the subject.

The first well that was executed of great depth, and which gave rise to the adoption of tools which directed public attention to the art of well boring was that for the city of Paris by M. Mulot, at the Abattoir of Grenelle (Plate 10). This was commenced in the year 1832, and, after more than eight years' incessant labour, in the course of which many inventions for facilitating the progress of the works, for removing the broken tools, for the introduction of the pipes, and for making observations at various depths from the surface, were resorted to, the water rose, on the 26th of February, 1842, from the total depth of 1,797½ feet. Subsequent to this, many wells have been sunk on the Continent, with the hope of attaining the brine springs so often met with in the Rhine provinces, or the springs destined for the supply of towns, and which are even deeper than the well of Grenelle, reaching in some cases to the extra-

ordinary depth of 2,800 feet; but all of them, like the Grenelle well, of small diameter. In them, however, the German Engineers introduced some important modifications of the tools employed; and, amongst other inventions, M. Euyenhausen imparted a sliding movement to the striking part of the tool used for comminuting the rock, so as to fall always through a certain distance; and thus, at the same time that he produced a uniform action upon the rock at the bottom, he avoided the jar of the tools. M. Kind also began to apply his system to the working of the large excavations for the purpose of winning coal mines; whilst the art was in this state, and when he had already executed some very important works in Germany, Belgium, the North of France, Creuzot, Seraing, &c., the Municipal Council of Paris determined to intrust him with the execution of a new well they were about to sink, at Passy (Plate 10), the Engineers advising the Municipal Council, that the process M. Kind proposed to adopt would enable him to finish the work rapidly, and with success. The well of Passy was intended to be executed in the Paris basin, which it was to traverse with a diameter, hitherto unattempted, of 1 metre (about 3 feet $3\frac{7}{16}$ inches); that of the Grenelle well being only 20 centimetres (about 8 inches). It was calculated that it would reach the water-bearing stratum at nearly the same depth as the latter, and would yield about the quantity of 8,000 metres or 10,000 metres cube per twenty-four hours, or about 1,786,240 gallons to 2,232,800 gallons per day.

The operations were undertaken by M. Kind under a contract with the Municipality of Paris, by which he bound himself to complete the works within the space of twelve months, from the date of their commencement, and to deliver the above quantity of water, for the sum of 300,000 francs (£12,000). On the 31st of May, 1857—after the workmen had been engaged nearly the time stipulated for the completion of the work, and when the boring had been advanced to the depth of 1,732 feet from the surface—the excavation suddenly collapsed in the upper strata, at about 100 feet from the ground, and filled up the bore. M. Kind would have been ruined had the Engineers of the town held him to the strict letter of his contract; but it was decided to behave in a liberal manner, and to release him from it, the town retaining his services for the completion of the well, as also the right to use his patent machinery. The difficulties encountered, in carrying the excavation through the clays of the upper strata, were found to be so serious, that, under the new arrangement, it required six years and nine months of continuous efforts, to reach the water-bearing stratum, of which time, the far larger portion was employed in traversing the clay beds. The upper part of this well was executed finally in a lining of solid masonry, to the depth of 150 feet from the surface; and, beyond that depth, tubing of wood and iron was introduced. This tubing was continued to the depth of 1,804

feet from the surface, and had, at the bottom, a length of copper pipe pierced with holes to allow of the entrance of the water. At this depth, the compound tubing could not be made to descend any lower; but the Engineers employed by the city of Paris were convinced, that they could obtain the water by means of a preliminary boring; and therefore they proceeded to sink in the interior of the above tube of 3 feet $3\frac{7}{16}$ inches in diameter, an inner tube 2 feet 4 inches in diameter, formed of wrought-iron plates 2 inches thick, so as to enable them to traverse the clays encountered at this zone. At last, the water-bearing strata were met with on the 24th of September, 1861, at the depth of 1,913 feet 10 inches from the ground line; the yield of the well being, at the first stroke of the tool that pierced the crust, 15,000 metres cube per twenty-four hours, or 3,349,200 gallons per day; it quickly rose to the quantity of 25,000 metres cube, or 5,582,000 gallons per day; and as long as the column of water rose without any sensible diminution, it continued to deliver a uniform quantity of 17,000 mètres, or 3,795,000 gallons per day. The total cost of this well was more than £40,000, instead of £12,000 at which M. Kind had originally estimated it, and the time employed has been considerably protracted.

The results of this well were so satisfactory, as far as regards the finding of the water and its quantity, that the town authorities of Paris have been induced again to entertain the project of resorting to the stratum from which it is fed, notwithstanding the diminution observed in the yield of the Grenelle well, and the singular variations remarked in the quality of the water of Passy. The Municipal Council have, in fact, decided to sink two Artesian wells immediately, and there are reports that they purpose to execute two others, at a future time. In the cases mentioned, the town authorities have been so far influenced by the criticisms of the public press, lately violently agitated against the employment of M. Kind and his inventions, that they have determined to intrust the work to French well-borers; and they have, at the same time, resolved to abandon the use of the tools employed by M. Kind, which differ in some remarkable peculiarities from those recommended by the French authorities. M. Laurent, the partner of the late M. Degoussé, and the continuer of his business, and M. Dru, the successor of M. Mulot, are the Engineers selected for the present undertaking. M. Laurent has, it must be confessed, already achieved considerable distinction, by the success of his operations, in sinking the Artesian wells lately executed by the French Government in the deserts of Northern Africa, and in the experimental boring at Highgate. The latter operation afforded a singular commentary on the uncertainty that must always attend the first experiments made to obtain water in the limits of any geological formation. M. Dru inherited the ex-

perience derived from M. Mulot, who had executed the first boring made in the Paris basin, and had subsequently exercised his profession in various parts of the world. It is not strange, then, that the Municipal Council should have selected these gentlemen to sink the new wells, in face of the failure that M. Kind had certainly made to perform his engagements with the city. The borings in the new wells will have about the same dimensions as in the experiment made by M. Kind, or about 1 mètre in diameter, so that they will be performed under nearly the same circumstances; but it is to be observed, that the experience gained as to the nature of the strata to be traversed, by the previous trials of MM. Mulot and Kind, must give MM. Laurent and Dru an advantage, by removing the uncertainty always attending the first operation. The systems of the French well-borers are now fairly upon their trial, and the question of the tools to be adopted in sinking wells through the Paris basin, the chalk, and the subcretaceous formations, will thus be solved practically.

The differences most apparent in the nature of the tools generally adopted in England and in France on the one side, and those introduced by M. Kind on the other, may be described in the following manner, so as to enable an Engineer engaged in this description of work to form an opinion on their respective merits, until circumstances shall arise to enable him to judge of their results by personal observation.

There are three systems in competition—the Chinese, or M. Fauvelle's system; the French well-borers', or, rather, the usual well-borers' system; and M. Kind's system. Of these, the system of M. Fauvelle was, at first, much patronized by M. Arago and by Dr. Buckland, but it is now very little practised on the Continent, and not at all in Great Britain. The principles upon which it was founded were, first, that the motion given to the tool in rotation was simply derived from the resistance that a rope would oppose to an effort of torsion; and, therefore, that the limits of application of the system were only such as would provide that the tool should be safely acted upon; and, secondly, that the injection of a current of water, descending through a central tube, should wash out the detritus created by the cutting tool at the bottom. The difficulties attending the removal of the detritus were enormous, and, though the system of M. Fauvelle answered tolerably well when applied to shallow borings, it was found to be attended with such disadvantages, when applied on a large scale, that it has been generally abandoned. The quantity of water required to keep the boring tool clear is a great objection to the introduction of this system, especially as in the majority of cases Artesian wells are sunk in such places as are deprived of the advantage of a large supply.

In the ordinary system of well-boring, the motion of the tools

used for the comminution, or for the removal of the rocks, is effected by the use of solid iron rods, connected with the upper parts of the machinery, so that the weight of the rods, and the weight of the tools themselves, increase in proportion to the depth of the excavation. It follows from this fact, that, where the excavation is very deep, there is considerable difficulty in transmitting the blow of the tool, in consequence of the vibration produced in the long rod, or in consequence of the torsion; and for the same reason, there is a danger of the blows not being equally delivered at the bottom. It has been attempted to obviate this difficulty by the use of hollow rods, presenting greater sectional area than was absolutely necessary for the particular case, in order to increase their lateral resistance to the blows tending to produce vibration. The trepan is made so as to fall from a height of 2 feet, but the disengagement of the machinery is effected by the reaction of the column of water that the trepan works in. The majority of well-borers have, in many instances, used the hollow rods filled with cork, or with similar substances, and they have also tried the Euyenhausen joint; but they do not appear to have made so much use of M. Kind's system for removing the products of the excavation, and they more frequently resort to augers and chisels.

In sinking the well of Passy, the weight of the trepan for comminuting the rock was about 1 ton 16 cwt. (1800 kilog.), the height through which it fell was about 2 feet (60 centimètres), and its diameter was 3 feet $3\frac{7}{16}$ inches (1 mètre). The rods were of oak, about 8 inches on the side, and the dimensions of the cutting tool were limited to 3 feet $3\frac{7}{16}$ inches because it worked all the time in water; but generally the class of borings M. Kind undertook were of such a description as justified the resort to tools of great dimensions. When sinking the shafts for winning coal mines, his operations required to be carried on with the full diameters of 10 feet or 14 feet; and he then drove a boring of 3 feet 4 inches diameter in the first instance, and subsequently enlarged this excavation. There can be no objection to executing Artesian borings of this diameter, other than the probable exhaustion of the supply; particularly as it is now known that the yield of water by these methods is proportionate to the diameter of the column; though, strange as it may appear, the first opposition to M. Kind's plan of sinking the well of Passy, was founded upon the assumption, that he would not meet with a larger supply of water from the subcretaceous formations, than had been met with at Grenelle, where the diameter of the boring was, at the bottom, not more than 8 inches. It is now, however, proved that there is a direct gain in adopting the larger borings, not only as regards the quantity of water to be derived from them, but also in their

execution, arising from the fact that the tools can be made more secure against the effects of torsion, or of concussion against the sides of the excavation, which is the cause of the most serious accidents met with in well-sinking.

The trepan of M. Kind contains some peculiar details, which merit a description in this place, and are shown in Plate 11, Figs. 1, 8, and 4. It is composed of two principal pieces, the frame and the arms, both of wrought iron, with the exception of the teeth of the cutting part, which are of cast steel. The frame has, at the bottom, a series of holes, slightly conical, into which the teeth are inserted, and tightly wedged up (Fig. 3). These teeth are placed with their cutting edges on the longitudinal axis of the frame that receives them; and at the extremity of the latter, there are formed two heads, forged out of the same piece with the body of the tool, which also carries two teeth, placed in the same direction as the others, but double their width, in order to render this part of the tool more powerful. By increasing the dimensions of these end teeth, the diameter of the boring can be augmented, so as to compensate for the diminution of the clear space caused by the tubing, necessarily introduced for security in traversing strata disposed to fall in, or for the purpose of allowing the water from below to escape at an intermediate level. Above the lower part of the frame of the trepan, is a second piece, composed of two parts bolted together, and made to support the lower portion of the frame; this part of the machinery also carries two teeth at its extremities, which serve to guide the tool in its descent, and to work off the asperities that may be left by the lower portion of the trepan. Above this, again, are the guides of the machinery, properly speaking, consisting of two pieces of wrought iron, arranged in the form of a cross, with the ends turned up, so as to preserve the machinery perfectly vertical in its movements, by pressing against the sides of the boring already executed. These pieces are independent of the blades of the trepan, and may be moved closer to it, or further away from it, as may be desired. The stem and the arms are, lastly, terminated by a single piece of wrought iron, which is joined to the frame with a kind of saddle-joint, and is kept in its place by means of keys and wedges. M. Kind introduced some modifications in the trepans employed in carrying out the large borings for the coal mines in Belgium. These were rendered necessary by the large dimensions he was obliged to give them, and by the preliminary use of a smaller trepan. He also introduced some precautionary measures to preserve the strictly vertical descent of the boring; but these require no especial notice. The whole of the trepan, above described, is finally jointed to the great rods that communicate the motion from the surface, by means of a

screw-coupling, formed below the part of the tool which bears the joint; this arrangement permits the free fall of the cutting part, and unites the top of the arms and frame and the rod (Plate 11, Fig. 2). It has been proposed to substitute for this screw-coupling a keyed joint, in order to avoid the inconvenience frequently found to attend the rusting of the screw, which often interposes great difficulties, in cases where it becomes necessary to withdraw the trepan.

The sliding joint is the part of Euyenhausen's invention most unhesitatingly adopted by M. Kind, and it is one of the peculiarities of his system, as contrasted with the processes formerly in use. So long as his operations were confined to the small dimensions usually adopted for Artesian borings, he contented himself with making a description of joint with a free fall; a simple movement of disengagement regulating the height fixed, by the machinery itself, like the fall of the monkey in a pile-driving machine; but it was found that this system did not answer when applied to large excavations, and it also presented certain dangers. M. Kind then, for the larger class of borings, availed himself of sliding guides, so contrived as to be equally thrown out of gear when the machinery had come to the end of the stroke, and maintained in their respective positions by being made in two pieces, of which the inner one worked upon slides, moving freely in the piece that communicated the motion to the striking part of the machinery. The two parts of the tool were connected, in fact, with pins, and with a sliding joint, which, in the Passy well, was thrown out of gear by the reaction of the column of water above the tool, unloosing the click that upheld the lower part of the trepan (Figs. 13, 14, and 15). The changes thus made in the usual way of releasing the tool, and in guiding it in its fall, were, however, matters of detail; they involved no new principle in the manner of well-boring; and the modern authorities upon the subject consider, that there was something deficient in M. Kind's system of making the column of water act upon a disc by which the click was set in motion. This system, in fact, required the presence of a column of water, not always to be commanded, especially when the borings had to be executed in the carboniferous series.

The rods used for the suspension of the trepan, and for the transmission of the blows to it, were of oak, and this alone would constitute one of the most characteristic differences between the system of tools introduced by M. Kind and those made by the majority of well-borers, but which, like the disengagement of the tool intended to comminute the rock, depended for its success upon the boring being filled with water. The reasons that M. Kind gives for the application of wooden rods appear to the Author, however,

to be worthy of more attention than they have generally received; for instance, M. Kind states, that he is enabled to secure greater rigidity and strength in these rods than he could by using iron rods of the same strength, and, that he is enabled to counterbalance them more exactly when they are working in water, so that nearly all the force exercised is employed in raising the trepan. The resistance that the wood offers, by its elasticity, to the effects of any sudden jar, is also to be taken into account in the comparison of the latter with iron, for the iron is liable to change its form under the influence of this cause. The resistance to an effort of torsion need not, however, be much dwelt on, for the turn given to the trepan is always made when the tool is lifted up from its bed. For the purpose of making the rods, M. Kind recommends that straight-grown trees, of the requisite diameter, should be selected, rather than that they should be made of cut timber, as there will be less danger of the wood warping, and the character of the wood will be more homogeneous. He generally uses these trees in lengths of about 50 feet, and he connects them at the ends with wrought-iron joints, fitting the one into the other. (Fig. 18.) The ironwork of the joints is made with a shoulder underneath the screw-coupling, to allow the rods to be suspended by the ordinary 'crow's-foot' during the operation of raising or lowering them. In the works executed at Passy, there was a kind of frame erected over the centre of the boring, of sufficient height to allow of the rods being withdrawn in two lengths at a time, thus producing a considerable economy of time and labour.

All the processes yet introduced for removing the products of the excavation must be considered to be, more or less, defective, because all are established on the supposition, that the comminuting tool must be withdrawn, in order that the spoon, or other tool intended to remove the products of the working of the comminutor, may be inserted. This remark applies to M. Kind's operations at Passy and elsewhere, as he removed the rock detached from the bottom of the excavation, by a spoon (Plate 11, Figs. 8 and 9), which was a modification of the tool he invariably employs for this purpose. It consisted of a cylinder of wrought iron, suspended from the rods by a frame, and fastened to it, a little below the centre of gravity, so that the operation of upsetting it, when loaded, could be easily performed. This cylinder was lowered to the level of the last workings of the trepan, and the materials already detached by that instrument were forced into the tool, by the gradual movement of the latter in a vertical direction. Some other implements, employed by M. Kind, for the purpose of removing the products of the excavation in the shafts for the coal-mines of the North of France, were ingenious, and well adapted to the large dimen-

sions of the shafts; but they were all, in some degree, exposed to the danger of becoming fixed, if used in the small borings of Artesian wells, by the minute particles of rocks falling down, between their sides and the excavation from above. Their use was therefore abandoned, and the well of Passy was cleared out with the spoon, the bottom of which was made to open upwards, with a hinged flap, which admitted the finer materials detached by the trepan. There were also several tools for the purpose of withdrawing the broken parts of the machinery from the excavation, or whatever substances might fall in from above; and all were marked by a great degree of simplicity, but they did not differ enough from those generally used by well-borers for the same purposes to merit further remarks. In fact, the accidents intended to be guarded against, or remedied are so precisely alike in all cases, that there can be little variety in the manufacture of these instruments. But the Author is rather disposed to believe that M. Kind has deprived himself of a valuable appliance in not using the ball-clack (la soupape à boulet) that other well-borers employ (Fig. 10). The tools used by MM. Mulot, Laurent, Dru, and other French well-borers (Plate 11), are admirably adapted for the extraction of the materials from excavations of small diameter, but would be of no avail if applied to the well of Passy. They seem to have been designed for wells which rarely exceed the diameter of that executed at Grenelle.

At Passy great strength was given to the head of the striking tool, and to the part of the machinery applied to turn the trepan, because the great weight of the latter superinduced the danger of its breaking off under the influence of the shock, and because the solidity of this part of the machinery necessarily regulated the whole working of the tool. The head of the 'assemblage' was connected with the balance-beam of the steam-engine by a Vaucauson chain, with a screw-coupling, admitting of being lengthened as the trepan descended. (Figs. 16 and 17.) The balance-beam, in order to increase its elastic force in the upward stroke, is usually, in M. Kind's works, made of wood, in two pieces; the upper one being generally of fir, and the lower one of beech. The whole of the machinery is put in motion by steam, which is admitted to the upper part of the cylinder, and presses it down, and thus raises the tool at the other end of the beam to that part in connection with the cylinder. The counterpoise to the weight of the tools is also placed upon the cylinder end of the beam. The cylinder receives the steam through ports that are opened and closed by hand, like those of a Nasmyth's hammer; so that the number of the strokes of the piston may be increased, or diminished, and the length of the strokes may be

increased as occasion may require. The balance-beam is continued beyond the point where the piston is connected with it, and it goes to meet the blocks, placed to check the force of the blow given by the descent of the tool. The guides of the piston-head are attached to the part of the machinery that acts in this manner; but in this instance M. Kind made the balance-beam work upon two free plummer-blocks, or blocks having no permanent cover, in order that they might be more easily moved whenever it was necessary to displace the beam, for the purpose of taking up, or letting down the rods, or for changing the tools; for the balance-beam was always immediately over the centre of the tools, and it therefore had to be displaced every time that the latter were required to be changed. This was effected by allowing the beam to slide horizontally, so as to leave the mouth of the pit open. The counter-check, above mentioned, likewise prevented the piston from striking the cylinder-cover with too great a force, when it was brought back by the weight of the tools to its original position. The operation of raising and lowering the rods, or of changing the tools, was performed at Passy by a separate steam-engine, and the spoon was discharged into a special truck, moving upon a railway, expressly laid for this purpose, in the great tower erected over the excavation. All these arrangements were, in fact, made with the extreme attention to the details of the various parts of the work which characterises the proceedings of foreign Engineers, and conduces so much to their success.

The beating, or comminution of the rock, was usually effected at Passy, at the rate of from 15 strokes to 20 strokes per minute. The rate of descent, of course, differed in a marked manner, according to the nature of the rock operated upon; but generally speaking, the trepan was worked for the space of about eight hours at a time, after which it was withdrawn, and the spoon let down, in order to remove the detritus. The average number of men employed in the gang, besides the foreman, or the superintendent of the well, was about fourteen; they consisted of a smith and hammerman, whose duty it was to keep the tools in order, and two shifts of men intrusted with the excavation, viz., an engine-driver and stoker, a chief workman, or sub-foreman, and three assistants. The total time employed in sinking the shafts executed upon this system in the north of France (where it has been applied without meeting with the accidents encountered in the Passy well), was found to be susceptible of being divided in the following manner: from 25 per cent. to 56 per cent. was employed in manœuvring the trepan; from 11 per cent. to 14½ per cent. in raising and lowering the tools; from 19 per cent. to 21 per cent. in removing the materials detached from the rocks, and cleaning out the

bottom of the excavation; and from 8 per cent to 10½ per cent. was lost, owing to the stoppage of the engines, or to the accidents from broken tools, or to other causes always attending these operations. In the well of Passy there was, of course, a considerable difference in the proportions of the time employed in the various details of the work; and the long period occupied in obviating the effects of the slips which took place in the clays, both in the basement beds of the Paris basin, and in the sub-cretaceous strata, would render any comparison derived from that well of little value; but it would appear that until the great accident occurred, the various operations went on precisely as M. Kind had calculated upon.

The essential difference between the systems of M. Kind and those of the ordinary well-borers, appears to consist in the use of a trepan of considerable diameter, falling through a certain height; and in the rods of oak, working in water, which were thus easily counterbalanced. All the other tools employed are, in point of fact, quite irrespective of the merits of the various processes. The advantages of these inventions would be very great, provided the well were sunk in such circumstances as would allow of its being worked under water; and the results of the Passy boring demonstrated that these inventions had a real existence, for the accidents attending that work were such as might have been expected in the course of boring Artesian wells. It may be questioned whether the Engineers of the town were justified in passing the contract with M. Kind, to finish the work within the time, and for the sum at which he undertook it; but they have certainly treated him with kindness and consideration, in allowing him to conduct the work at the expense of the city of Paris, for so long a period after the expiration of his contract. It seems, however, that the French well-borers could not, at the time, have attempted to continue the well upon any other system than that introduced by M. Kind; that is to say, upon the supposition that it should be completed of the dimensions originally undertaken. The patent has now expired, and the processes he introduced have consequently been open to the imitation of all the world, and no doubt they will be adopted by the French well-borers. Indeed, from some passages in a work by M. Degoussé, it may be inferred that he is about to employ the peculiar tools used by M. Kind for the boring of the well of Passy. M. Dru has, in the meanwhile, introduced a "free fall" for the trepan; but it must be confessed, that the style of tubing of wood and iron, which M. Kind preferred in the upper part of the boring was justly criticised by all who spoke at the meeting of the "Société des Ingénieurs Civils;" experience has shown, in fact, that this detail was badly executed at the well of Passy. The masonry lining was introduced after his

contract had expired, and when he had ceased to have the control of the works; the wrought-iron tubing at the lower part of the excavation being a subsequent idea. It has followed from this defective system of tubing (the wood, necessarily yielding in the vertical joints) that the water, in its upward passage, escaped through the joints, and went to supply the basement beds of the Paris basin, which are as much resorted to as the London sand-beds for an Artesian supply; and, in fact, the level of the water has been raised in the neighbouring wells, by the quantity let in from below, and the yield of the well itself has been proportionally diminished, until it has fallen to 450,000 gallons per day. That the increased yield of the neighbouring wells is to be accounted for by the escape of the water from the Artesian boring is additionally proved by the temperature of the water in them; it is found to be nearly 82° Fahr., or nearly that observed in the water of Passy. This was an unfortunate complication of the bargain made between M. Kind and the Municipal Council; but it in no respect affects the choice of the boring machinery, which seems to have complied with all the conditions it was designed to meet. The descent of the tubes, and their nature, ought to have been the subject of special study by the Engineers of the town, who should have known the nature of the strata to be traversed, better than M. Kind could be supposed to do, and should have insisted upon the tubing being executed of cast or wrought iron, so as effectually to resist the passage of the water. At any rate, this precaution ought to have been taken in the portions of the well carried through the basement beds of the Paris basin, or through the lower members of the chalk, and the upper green sand. It may also be observed, that a remarkable change has been noticed in connection with the subterranean disturbances which have lately taken place in France. The water in this well is, at these times, rendered thick, cloudy, and totally unfit for human consumption. The discolouration of the water, however, is not dependent upon this cause, but is owing to the strata through which the boring passes, being washed out, which is in itself a serious objection to the use of the water of this well.

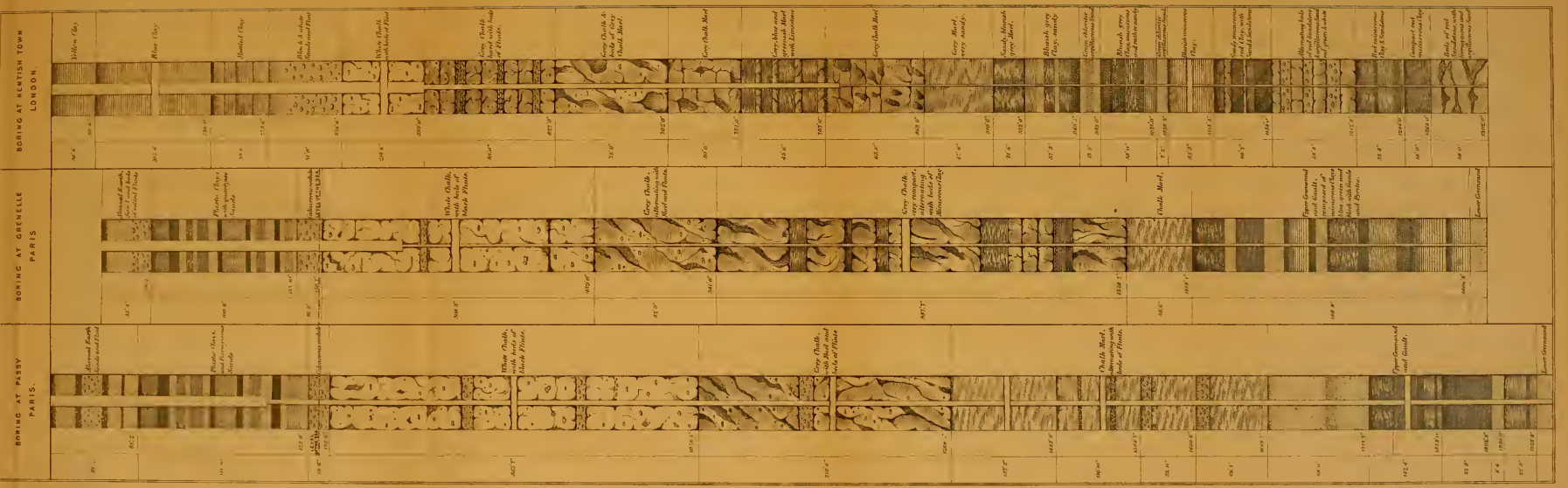
The system applied by M. Dru is worthy of attention, not so much on account of the novelty of the invention, or of any new principle involved in it, as on account of the contrivances it contains for the application of the tool, 'à chute libre,' or the free-falling tool, to Artesian wells of large diameters. It has been already explained, that under M. Kind's arrangements, the trepan was thrown out of gear by the reaction of the water which was allowed to find its way into the column of the excavation; but that it is not always possible to command the supply of the quantity necessary for that purpose; and even when possible, the clutch

M. Kind adopted was so shaped, as to be subject to much and rapid wear. M. Dru, with a view to obviate both these inconveniences, made his trepan in the manner shown in Plate 11, Fig. 13, in which it will be seen that the tool was gradually raised, until it came in contact with the fixed part of the upper machinery, when it was thrown out of gear. The bearings of the clutch were parallel to the horizontal line, and were found in practice to be more evenly worn, so that this instrument could be worked, sometimes, from eight days to fourteen days without intermission; whereas on M. Kind's system, the trepan was frequently withdrawn after two days' or three days' service. Another great recommendation of M. Dru's system, if applied in cases where water is scarce, is that there is no necessity for a column of water with the trepan; but in all other essential respects the details of his machinery are the same as those employed by M. Kind, who must be considered to have advanced the science of well-boring by the introduction of timber-rods, the manner of balancing them, and by the use of the trepan, all of which were first applied at the Artesian boring of Passy, and enabled it to be executed in a comparatively short space of time. The tools introduced by M. Dru, and other modern well-borers, are doubtlessly better fitted for the Artesian borings of small diameter, and for such as are free from water from the upper strata; but the advantage ceases when these conditions are reversed, as they will be in the new wells which the city of Paris is about to undertake. For these, in the Author's opinion, M. Kind's system, modified and perhaps improved in some of its working details by the trials it has undergone, is the best. The interest with which the progress of the wells at Paris will be watched will now be the greater, inasmuch as the various implements, as well as the correctness of the principle of resorting to this source of supply, are being tested. The differences discoverable in those at present employed are, after all, only in matters of detail that may be easily explained by the lessons of experience in the course of the works. As to the principles involved in the construction of the tools, the real merit is due to Euyenhausen, who invented the free-falling tool, and to M. Kind, who introduced the system of counterbalancing the weight of the rods, made of wood, for this purpose.

It may be added, that the city of Paris has decided on sinking the wells through the basement beds of the basin, so that the borers will begin their operations at once in the chalk, without encountering the difficulties that have hitherto opposed the progress of the work, in consequence of the falling in of the strata of sand and clay. In the well about to be sunk at La Villette, it is said that the town will have thus to execute a depth of 180 feet at its

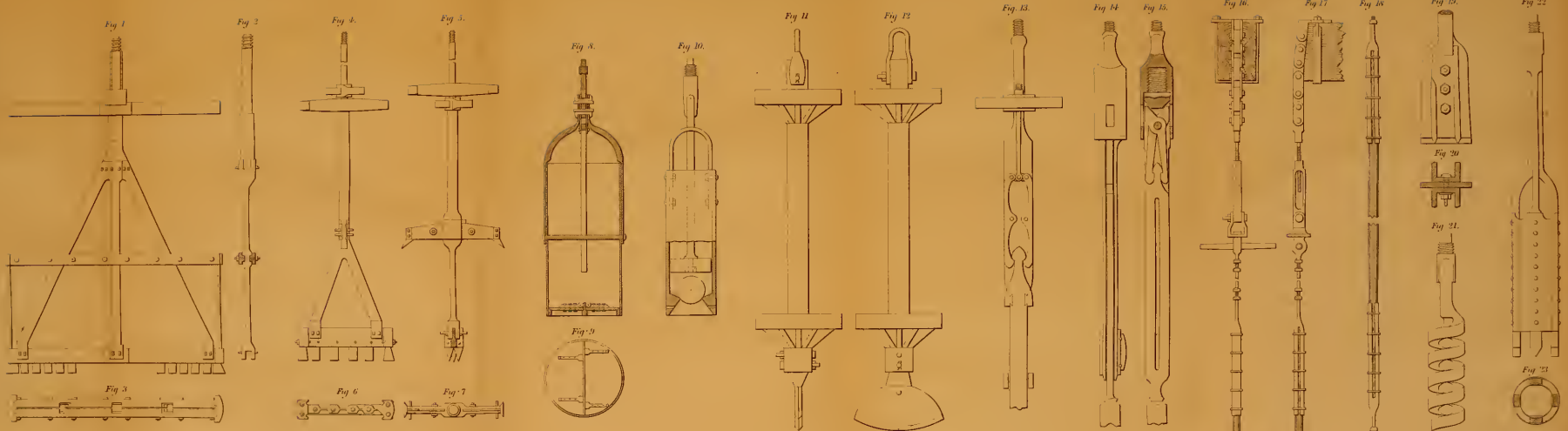
own risk. The elimination of this cause of disturbance will, however, prevent the establishment of a perfectly satisfactory comparison between the systems of M. Kind and his rivals, by withdrawing, from the proceedings of the latter, one great element of uncertainty.

The Paper is illustrated by a series of diagrams, from which Plates 10 and 11 have been compiled.


BORING AT KENTISH TOWN LONDON.
Yellow Clay.
Blue Clay.
Mottled Clay.
Black Carbide Sand and Pebbles.
White Chalk with Beds of Flints.
Grey Chalk & Marl with Beds of Flints.
Grey Chalk Marl.
Grey Chalk Marl very sandy.
Sandy Micaceous Stone Marl.
Micaceous Stone Marly sandy.
Micaceous Stone Marl.
Sand, micaceous and Clay, with Coal & Lignite.
Coal.
Compact red micaceous Clay.
Red micaceous Clay & Sandstone.
Micaceous Stone Marl.
Grey Chalk.
Chalk Marl.
BORING AT GRENELLE PARIS.
Alluvial Earth, Sand and Gravel.
Plastic Clays with green sand Grains.
Calcareous sandstone.
White Chalk with beds of black Flints.
Grey Chalk alternating with Marl and Flints.
Grey Chalk very compact, alternating with Layers of Micaceous Clay.
Chalk Marl.
Lower Greensand and Gault, composed of Micaceous Sand, green sand Marl, with beds of Flints.
Lower Greensand.
BORING AT PASSY PARIS.
Alluvial Earth, Sand and Gravel.
Plastic Clays, and Ferruginous Gravels.
Calcareous sandstone.
White Chalk, with beds of black Flints.
Grey Chalk, with Marl and beds of Flints.
Chalk Marl, with beds of Flints.
Upper Greensand and Gault.
Lower Greensand.

ARTESIAN WELLS.

TOOLS USED IN WELL-BORING.



Mr. VIGNOLES said, this subject was one to which he had paid great attention for many years, and he would make a few remarks, rather by way of explanation than of criticism, excepting that he would demur to the definition the Author had given in styling the 'Fauvelle' system a Chinese system. The Chinese system, with which he was familiar, and that of 'Fauvelle' were distinct. The principle in boring used by the Chinese, as appeared from records of 1,500 years ago, was simply that of percussion; the borer, having been drawn up to a certain height by a rope passing over a pulley, acted by its weight, and the rotary action of the rope enabled the tool to fall successively on different parts. To this system Fauvelle added the contrivance of introducing a stream of water to force up the debris and avoid the necessity of using the shell pump. On a small scale that contrivance had proved successful.

At the meeting of the British Association at Southampton in 1846,[1] he read a description of that system, and when he was at Perpignan, eighteen years ago, he saw it in operation, and in the strata which the apparatus had then to work in, it did well. He agreed with the Author, that in boring for water it was not always possible to get a supply to work the machine, but the quantity required was so small in comparison with the results, that he thought the Fauvelle system might be advantageously adopted.

With respect to the machinery introduced by M. Kind, the principle of it had been well known in Germany for many years. It was now between twenty-five years and thirty years since he examined into that principle, in the coal-fields near Zweibrucken, at which time holes of 18 inches diameter were being bored. Since that period it had been carried to such an extent, that in October last, in the Moselle coal-fields, on the eastern frontier of France, wells were bored at least 9 feet in diameter. The practice was, to make a beginning with an interior cutter of a smaller size, and immediately follow it by a larger concentric one, of the kind described in the Paper; and he believed a depth of 500 feet or 600 feet had been successfully reached through the rock. The average rate of working was half a mètre, or about 20 inches per day.

The system of boring in Paris, and elsewhere, might be divided into two parts—first, the method, and the precautions adopted in passing through the upper and softer strata, to prevent the falling of the material into the tubing; and then the application of the system of boring described in the Paper. He thought the two were distinct. The peculiar system introduced by the

[1] *Vide* "The Civil Engineer and Architect's Journal," vol. ix., p. 305.

authorities and the contractor for the well at Passy was applicable in hard soils; in the softer soils it was perhaps doubtful whether it could be so successfully applied.

The experience gained in France and Germany, particularly in sinking for minerals, was very great; for in those countries not merely the air shafts, but also the working shafts, were being sunk; and the precision, accuracy, and economy with which pits were sunk of that large diameter, on this principle, were remarkable. Therefore, he conceived, it might be applied to borings for Artesian wells on the moderate scale to which it was necessary to confine it in order to work it economically.

There was no doubt, however, that there was greater economy in working upon the larger scale, such as was required for coal pits, than upon the smaller scale for wells, inasmuch as many of the precautions and apparatus required upon a large scale were necessary on a small scale. That the general result would be the adoption of that system of boring, he had no doubt; for it was quite clear, from the knowledge acquired on the Continent, particularly in the case of coal-mines, and in the well at Passy, that, although there were difficulties in working by percussion, this system might be followed with great economy and propriety. But, while he admired the extreme ingenuity with which all the details of construction were carried out by foreign Engineers, he thought if this system were adopted by the English well-borers, their practical experience would enable them to carry it out with still greater economy. The adoption of timber rods, which, however, had long been used in Cornwall for pumping, he considered was an improvement, in respect of lightness and facility of working.

Mr. S. C. Homersham had given attention practically to this subject for many years. He had sunk several borings of 18 inches diameter by steam machinery, and he was now executing a boring 2 feet in diameter by the same means. On December 30th, 1861, he commenced boring at the bottom of a well 180 feet deep, in the red sandstone at Middlesborough, and for some time he proceeded at a rate varying from 13 feet to 15 feet per day, and in 532 working days he reached a further depth of 1,132 feet. This made as nearly as possible 2 feet 1½ inch for each working day, including all stoppages from whatever cause.

The system employed was something like that described by Mr. Vignoles. The boring head, which was about 18 inches in diameter, was hung by a rope passing over a pulley connected with the piston-rod of a steam cylinder. When the steam was let out of the cylinder, and the piston fell, the boring head, containing the boring tools, also descended upon the rocks by its own gravity, and the hardest blow was struck that the weight of the boring head and tools descending by their gravity could inflict. The

force of the blows was regulated by adjusting the escape of the waste steam from the cylinder. When the escape valve was closed at a certain point, a cushion of steam was formed between the piston and the cylinder cover, and a blow might thus be given either of extreme delicacy, or of the force of 20 cwt. falling upon the stratum from a height of 5 feet, or 6 feet. The machine employed was constructed by Messrs. Mather and Platt, of Manchester. The debris was cleared out by means of a shell pump, in a superior manner to anything he had hitherto seen. At the bottom of the shell was a valve of solid india-rubber, opening inwards; the piston, which quite filled the pump, was solid at the side, without packing, and had a valve opening outwards. When the shell was lowered to the bottom of the bore hole, the piston fell, and was then pulled suddenly up by the rope acted upon by the piston in the steam cylinder. A vacuum was thus created inside the shell pump, and the debris was carried by the current of water into the inside of it. By this means pieces of rock of considerable size and great weight, and even pieces of lead, were readily brought up from borings 1,100 feet or 1,200 feet deep, or from even a greater depth. This system had been tried successfully in many places and in different kinds of rock.

He had not seen the continental system in operation, but he considered the system of Messrs. Mather and Platt superior to the methods of boring described in the Paper, or, indeed to any other with which he was acquainted. In a dry stratum, however, Messrs. Mather and Platt's system could not be used. In Lancashire and Yorkshire it had been adopted extensively, and there was one well in the red sandstone at Manchester, yielding between three millions and four millions of gallons per day, which had been sunk on this system. When not interrupted by water, no doubt by far the better way was to sink wells or small shafts by manual labour, by which means the work was done cheaper, more expeditiously, and better, than could be done by any sort of machinery at present in use.

Mr. MATHER directed attention to specimens of rock, &c., which had been excavated with the machine which had just been described. This machine, since 1854-5, had bored sixteen or seventeen holes, making a total of 9,000 feet, from 15 inches in diameter, up to 2 feet in diameter; and a machine was now being made to bore a well 3 feet in diameter. The accounts as to the results were perfectly accurate, and coincided with the records of the borings already carried out. In one instance a boring had been carried to a depth of 1,100 feet. The first portion was 18 inches in diameter, but afterwards it was increased to 21 inches for the whole depth. A depth of 900 feet of boring was executed in four months. The advantages of this machine had been shown in

borings in the red sandstone, which had been executed at the rate of from 15 feet to 30 feet per week. A bore-hole in the Yorkshire stone, at Bradford, had just been completed, and a depth of 460 feet was attained, in seven months from the time of starting the work; and, from the specimens exhibited, it would be seen that the stone, being millstone grit, required very hard boring to bring it up. In the hardest rock at Bradford the progress was from 4 feet to 10 feet per week. The Middlesborough boring, for a depth of 500 feet, was executed at the rate of 50 feet per week; beyond that depth, the strata being harder, the speed decreased; but during the whole progress of the work, the rate was much greater than that shown by the records of Continental borings.

The system of M. Kind was no doubt ingenious. He had seen it in operation at Moscow, in an experiment as to whether a supply of water from an Artesian well was practicable there. The work, to the depth of 940 feet, was completed in two years. Comparing that rate of progress with the experience of similar works in England, it might fairly be said that an equal depth might be reached within twelve months. There appeared to be, under M. Kind's system, great loss of time in drawing out the rods, in removing the tool, and in clearing away the debris, which was avoided by the plan of boring with a flat rope; with this method, when the boring-head had descended, the striking cylinder was set in motion, and struck a number of blows on the rock. The rope, to which the boring-head was attached, passed over a pulley in the fork of the piston-rod of the striking cylinder; and as the piston-rod rose and fell, by admitting and exhausting the steam in the cylinder, the rope and head were drawn up and let fall, when the cutters in the latter struck the rock and broke it up into pieces, which the pump afterwards removed. As the boring-head struck, a slight twist was given to the rope, by a mechanical contrivance in the boring-head itself, so that when the strain came on again in lifting, the rope, in regaining its proper position, twisted the boring-head slightly round, and thus prevented the cutter from striking always in the same place. When a sufficient number of blows were given by the striking cylinder, the steam was shut off, and then the rope was drawn up and wound upon a large drum, by means of a separate engine, in the same way as in colliery shafts. The boring-head being removed, the pump was attached to the rope, and let down into the hole by the winding engine. When at the bottom, several rapid strokes were given, by winding the rope quickly up and letting it out again. In this way the cylinder of the pump was filled with the broken rocks, &c., and then brought to the surface to be emptied. This was repeated till the hole was found to be empty, and then the boring-head was put down again. The working of this machine required the attendance of only one

leading man and three labourers, for changing the head and clearing out the hole with the pump.

Mr. VIGNOLES said, that twenty-five years ago, on the Manchester and Sheffield Railway, he had used percussive action, by means of a tool at the end of the rope, as well as the shell pump for drawing up the debris, of the same description as that just alluded to, except that it was done by hand labour instead of by steam power. He had no doubt Messrs. Mather and Co. had introduced some improvements, of which the application of steam might be the chief; but in principle it was the same as the Chinese had used fifteen hundred years ago. He should be glad to be informed of the cost of the borings spoken of, because in early days, a boring of 6 inches or 8 inches in diameter was considered enormous; but at the present time borings of 18 inches or 2 feet in diameter were common in many parts of the Continent.

Mr. MATHER replied, that the cost would necessarily vary according to the nature of the strata to be bored through. At Stockport, a bore hole 18 inches diameter, and 420 feet deep, had been completed, and the total amount received for that was £240; but that could scarcely be taken as a datum of the cost of boring. Sometimes the expense would be 10*s*. per foot; at others it would be £5 or £6 per foot.

Mr. BEARDMORE inquired if he understood the Author to state, that the tool remained eight hours at work without being lifted from the hole.

Mr. BURNELL replied, that was so through an average of working.

May 31, 1864.

The Session was concluded by a Conversazione, at which the President received the Members of the Institution, and a numerous circle of distinguished visitors. The rooms were decorated with many choice works of art, and there was also exhibited a large and interesting collection of mechanical models.

APPENDIX TO VOL. XXIII.

MEMOIRS.

THE RIGHT HONOURABLE JOHN SINGLETON COPLEY, Baron Lyndhurst, LL.D., High Steward of the University of Cambridge, F.R.S., &c., was born at Boston, "in his Majesty's North American Colonies," on the 21st of May, 1772. His father was John Singleton Copley, the distinguished artist, who, emigrating from Ireland, had sought fortune in the Colonies, not foreseeing the revolution which was destined to drive him, with many other loyalists, back to their mother country. The family did return and settle in London in 1774, and in due time the younger Copley was sent to attend the lectures of Reynolds and of Barry. He had not, however, any vocation for the career of an artist, and at the age of nineteen he was entered at Trinity College, Cambridge, where he greatly distinguished himself by his proficiency in mathematics, taking high honours, and eventually becoming a Fellow of his college. He also cultivated, to a degree little known and appreciated at that time, his taste for chemistry and mechanics, in both of which he was subsequently considered an adept, and his knowledge thus acquired was eventually of signal assistance to him in his legal career. From the lectures of Professor Farish he had imbibed great taste for practical mechanical construction, and even after his elevation to the woolsack, his box of tools afforded frequent amusement for his leisure hours.

He was called to the bar by the Honourable Society of Lincoln's Inn on the 8th of June, 1804, went the Midland Circuit, had chambers in the Temple, and soon attained the reputation due to his talent and severe training. In 1813 he became a Serjeant-at-law, and soon after a well-known case respecting a patent for making lace, in which Mr. Heathcote, M.P., was interested, brought out his scientific acquirements, and at once established his forensic reputation.

In 1818 he took his seat in the House of Commons, as Member for the Borough of Yarmouth, in the Isle of Wight. In the same year he was appointed Chief-Justice of Chester, and in 1819 he became King's Serjeant, and speedily afterwards Solicitor-General,

and received the honour of Knighthood. Previously having, with Sir Charles Wetherell, defended some of the political criminals in the Thistlewood trials, it became his duty to prosecute his former client, Thistlewood, for the Cato Street conspiracy, a task which he performed with singular tact. It was also his duty to take a part in the proceedings against Queen Caroline, and by his judgment and moderation he contrived to escape the censure which was freely bestowed on some of his colleagues. Subsequently he sat for Ashburton and for the University of Cambridge, taking, on several occasions, marked positions in public events, and affording considerable assistance to his colleagues in the House.

In 1826 he became Master of the Rolls, and in 1827 he attained the position of Lord Chancellor, and was created Baron Lyndhurst. In the Upper House his calm and dignified elucidation of any subject under debate was fully appreciated, and he very soon made himself known in the House of Lords as a political notability.

His legal career has been described by Lord Campbell in the 'Lives of the Chancellors,' his political life has still to be written, when the ancient distinctions of Whig and Tory shall have entirely disappeared. His official life was unusually long, and at its close, when he naturally assumed the position of the Nestor of the House —"the old man eloquent,"—his opinions, when untrammelled by party views, were respected by all. His fame arose from his brilliant wit, his matchless irony, his terrible invective, his apt quotations, his polished style, and perfect diction. His oratory was the result of careful preparation, his articulation was melodious, and his voice perfect, clear, and silvery. His statement of a case was as clear as his perception of it. He carefully avoided giving offence by his manner, and he won golden opinions by his never-failing tact and urbanity. His long public life was appropriately brought to a close on the 5th of July, 1859, by his magnificent speech on the National Defences, when, in spite of the mental and physical wear and tear of eighty-eight years, he exhibited unrivalled brilliancy of eloquence and undiminished clearness of reasoning; whilst the "*Væ victis*," with which that great monition concluded, has found an echo in the tramp of the Volunteers and the thunder of the hammers on our iron-plated ships; and by all parties it is admitted that John Singleton Copley deserves the highest niche in the temple of legal statesmen, in respect of brilliant oratory, profound learning, varied accomplishments, generous disposition, and unquestionably pure patriotism.

Lord Lyndhurst was elected an Honorary Member of the Institution of Civil Engineers "because of his attachment to engineering pursuits, and his knowledge of mechanical science," June 28th, 1842, and his decease occurred October 12th, 1863.

Mr. WILLIAM TOOKE, F.R.S., was the second son of the Rev. William Tooke, an English Divine, who was the Chaplain of the factory of the Russian Company at St. Petersburg, where he, among other works, wrote the 'Life of Catharine II.,' 'A View of the Russian Empire.'

William Tooke, junior, was born at St. Petersburg, on the 22nd November, 1777, and, after the usual course of study, was admitted as a solicitor, and practised his profession for many years with considerable success, acquiring a high reputation.

Science, art, and literature had for him great attractions, and he devoted to them all the spare time of the best years of his life. He was attached to the society of the literary men of his day, and there were few persons better known than he was as the founder and promoter of literary and scientific associations throughout the country. In conjunction with Lord Brougham, Dr. Birkbeck, Mr. Grote, and others, he took a very active part in the establishment of the Society for the Diffusion of Useful Knowledge, of which, for some years, he acted as the Treasurer. He was for many years a leading Member of the Society of Arts, filling consecutively almost every post in connection with the Council, and holding for a time the position of President, after the decease of the Prince Consort.

He was a Fellow of the Royal Society, and a Member of several other societies. From 1832 to 1837 he represented in Parliament the borough of Truro.

In early life he contributed, anonymously, many articles to the Magazines, and he edited an edition of Churchill's Poems, with notes and a Life of the Author, which was favourably reviewed by Southey, and was subsequently reprinted with Mr. Tooke's name on the title page. He also published, in 1855, a compilation on French History, entitled 'The Monarchy of France, its Rise, Progress, and Fall;'[1] a curious book in these times, if read with a good knowledge of the present state of Imperial France.

At a very early period in the history of the Institution of Civil Engineers, Mr. Tooke, who had been brought by his professional engagements into contact with Mr. Telford, became interested in the progress of the young Society; he attended the meetings as a visitor, and in 1828, when there was a question of obtaining a Royal Charter, he not only gave good advice, but he obtained the Royal grant with comparatively very small cost. In 1838 he was formally nominated the Honorary Solicitor of the Institution, and was annually re-elected during the remainder of his life. He was also elected an Honorary Member in 1849. He was ever ready to give his best assistance in every way, and in the most liberal manner, and the Society has still the advantage of the same kind

[1] Library Inst. C.E.

co-operation from his professional successors, Messrs. Tooke, Hallowes, and Price.

Mr. Tooke was a man of great energy, of strong party feeling of the old school of politics; he delighted in doing good practically, and spared neither time nor labour to accomplish his object. He was deservedly very successful; and at his decease, which occurred September 20th, 1863, in the 86th year of his age, he left a blank in a large circle which will be long felt.

Mr. THOMAS EVANS BLACKWELL was born at Devizes, on the 28th of July, 1819. His early mathematical training and his best impressions were derived from his godfather, the Rev. Thomas Evans, at that time Vicar of Froxfield—the "Felix Ford" of the early numbers of the 'Mechanics' Magazine,' and who was formerly connected with the Royal Military Academy, Woolwich. Young Blackwell having obtained a liberal education, commenced his professional career under his father, the late Mr. John Blackwell, who was for many years Engineer to the Kennet and Avon Canal Company. Thus he had the advantage of a large share of active out-door employment on the works of that navigation, and on the rivers Kennet and Avon, as well as a thorough training in mathematics and in the theory of the profession. His attention to the works intrusted to his care, and the talent he exhibited in design and construction, procured him many friends; and on the death of his father, he was, at the early age of twenty-one years, appointed Engineer to the Kennet and Avon Canal Company. In 1840-41, during the diversion of the canal, near Bath, for the purpose of forming a portion of the Great Western Railway, in an adjacent deep cutting, he shared a deep responsibility, in conjunction with the late Mr. I. K. Brunel, the Engineer-in-Chief, and Mr. Frere, the resident Engineer, in keeping open the navigation.

Mr. Blackwell's practical sagacity enabled him to see, at an early period in the development of the railway system, that on such a line of country as that between London and Bristol, the railway must eventually supersede canal and river carrying; and he recommended the Directors of the Kennet and Avon Canal Company to convert it into a railway. In 1845, he was instructed to prepare the necessary plans for an application to Parliament for this purpose. This scheme, which would have provided a second line of railway between Bristol and Reading, was strongly opposed by the Great Western Railway Company, who, for a time, postponed the construction of the new line by the purchase of the canal. Railways running through nearly the same line of country have since been made, of one of which

—the Bradford and Bathampton Branch of the Wilts, Somerset, and Weymouth Railway—Mr. Blackwell was resident Engineer, until its amalgamation with the Great Western Railway.

In the year 1852, Mr. Blackwell was appointed Engineer to the Bristol Docks—an appointment he retained until his departure from England to take charge of the Grand Trunk Railway of Canada, in 1857. During his connection with Bristol, he was frequently consulted by the corporation of that city on general works; and, in the year 1854, when an accident occurred, by which the cast-iron bridge, built by Jessop, for carrying the Bath and Wilts turnpike road over the river Avon, was destroyed, he met the emergency, by designing and carrying out, in a very short time, a new wrought-iron girder bridge of 100 feet span, and of an ornamental character. In conjunction with the late Mr. Rendel (Past President Inst. C.E.), he designed, in 1852, plans for constructing a railway from Bristol to the mouth of the Avon, together with extensive docks at the mouth of the river for the accommodation of the largest class of ocean-going steamers; and, in 1853, he was engaged to prepare plans for a railway between Bristol and the New Passage on the Severn, with a steam ferry to connect Bristol with South Wales. These works, postponed for a time, have, with some modifications, since received the sanction of Parliament.

He was a Member of the Geological, the Geographical, the Meteorological, and other Societies, and, having a good knowledge of mining, was frequently consulted on the probabilities of finding coal, and other minerals, and on the management of collieries, in the Bristol district.

In the practice of his profession, Mr. Blackwell's attention was more especially given to works connected with canal navigation, and he was frequently engaged in arbitrations and cases of dispute connected with water rights. In cases involving the gauging of streams, or other waters, he felt, in common with many Engineers, the want of data on a larger and more practical scale than had been hitherto established for determining the coefficients to be used in formulæ for such calculations; and, in 1850, he undertook and carried out, on the Kennet and Avon Canal, an extensive "Series of Experiments on the Discharge of Water by Overfalls or Weirs," the results of which, and of some others, undertaken in conjunction with Mr. James Simpson (Past President Inst. C.E.), were communicated to the Institution of Civil Engineers,[1] in a Paper for which he received a Council Premium. Mr. Blackwell was for many years Consulting Engineer to the Severn and Wye Railway and Canal, Forest of Dean, and

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. x., p. 331.

for some time Engineer to the Glamorganshire Canal, and was occasionally consulted on the Stourbridge, Market Weighton, and other canal works. He was also at different periods engaged in cases relating to the Birkenhead and Tyne Docks; the Bristol, Bath, Wolverhampton, and Gloucester Waterworks; and the drainage of the towns of Reading, Sandgate, and Devizes, of a district near Harwich, and of the lower level of the county of Gloucester. He was also one of the three Commissioners appointed by Government, on the 31st December, 1856, "to consider the plans for the Main Drainage of the Metropolis, as submitted to the First Commissioner (of Her Majesty's Works) by the Metropolitan Board of Works."

In 1857, Mr. Blackwell went to Canada, as vice-president and general manager of the Grand Trunk Railway, an appointment which he held until 1862, when, on his retirement, a handsome testimonial was presented to him by the working staff, with an expression of their warm attachment, and of their sincere and unanimous regret at his departure. Previous to returning to England, in June, 1862, he made an extensive tour in the United States, and formed a large acquaintance with American citizens eminent in their various departments. When he arrived in England, he was then so much disabled, by the disease which was destined to prove fatal, as to be unfit for active employment, and during the greater part of the remainder of his life he was more or less an invalid. In the spring of the following year, influenced probably by the listlessness and desire to escape from self which long-continued and unrelieved suffering is apt to inspire, and partly also, perhaps, by the vague but vain hope of benefit from change of climate and scene, he carried out a wish he had long entertained of visiting Egypt, ascended the Nile, and spent some time, on his return, at Rome and Naples. But it became necessary to hasten home, as his illness had become much aggravated. The second day after his arrival, he took to his bed, which he never afterwards left, and he died on the 25th June, 1863, in the 45th year of his age.

The disease of which Mr. Blackwell died was chronic inflammation of the membranes of the spinal cord, extending to that part of the base of the brain in connection with it; post-mortem examination showed the disease to have been both severe and of long duration. The symptoms during life had been extremely obscure and perplexing as to the real nature of the case, though of unusual severity in themselves. The form assumed by the symptoms was that of attacks of agonizing pain in the chest, resembling those of *angina pectoris*, lasting for some hours, and recurring at short intervals, until they passed off. The first attack occurred in February, 1860, and was of short duration. He

did not experience another until the following December; but this was of such severity and continuance that his life was despaired of. After this, they returned at intervals of a few months, each series of attacks lasting for some days, and leaving him almost in his usual health during these intervals. They, however, gradually increased in frequency, and in his last illness they continued for a month, with only such short intermissions as the most powerful means of alleviation could afford, when he died apparently from exhaustion. It has been suggested that the arduous, anxious, and harassing nature of the duties in which Engineers are so often engaged, especially in critical and important works, involving unceasing and trying attention, must be unfavourable to longevity. The special circumstances of Mr. Blackwell's case, which might be mentioned as having had a possible connection with his disease were, first, a railway accident, in which he was a sufferer in 1851, and which, though not apparently attended with any direct injury, was followed by symptoms indicating that a severe shock had been sustained by the nervous system; secondly, a large amount of railway travelling, which, as is known, has been ascertained to have a special tendency in many persons to the production of special disease; and lastly, a large amount of professional wear and tear, especially during the period of his connection with the Grand Trunk Railway of Canada. The first attack occurred during the third year of his management of that undertaking, and at a time when he was undergoing a great amount of work and anxiety.

In character, Mr. Blackwell united a kind, generous, and enterprising disposition, with intellectual powers of no common order. His scientific attainments were varied and extensive, and he used them well in the practice of his profession. He was a good geologist, had a considerable knowledge of the fine arts, and by his amenity of manner, possessed the happy tact of convincing those who were opposed to his views, as much by conciliation as by argument. In all the relations of life he was no less beloved than esteemed.

Before leaving Canada, Mr. Blackwell collected, at great expense, a large amount of information relating to the hydrology of British North America, particularly of the basin of the river St. Lawrence. That inquiry includes notes on the geology, topography, meteorology, rivers and waters, facilities for navigation, products and trade of the district investigated, and the results will even yet, it is believed, be published. He had purposed to present to the Institution of Civil Engineers a Paper on a branch of this subject—that relating to the river St. Lawrence, with an account of the navigation through the river, its lakes, and canals. He was also about to publish a comprehensive

work on the iron-producing capabilities and districts of North America, the map to illustrate which was carefully made on a large scale, and was considered so valuable by the American Coast Survey Department, at Washington, that before its removal from that country, permission was sought and granted for a photographic copy to be taken of it. Mr. Blackwell was the Author of several inventions, among which, an improved aneroid barometer, of extreme delicacy, takes perhaps the first place, and of it Mr. James Glaisher stated: "I have compared the readings of two of Mr. Blackwell's aneroid barometers with those of the standard barometer, at the ordinary pressure of the atmosphere, during the last three or four months, and I have found them to be exceedingly sensitive and accurate; the most accurate aneroid barometer, perhaps, which I have ever examined. Briefly, I may add, that I am led to form a very favourable opinion of these instruments by their exceeding sensitiveness and accuracy."

This was confirmed by Mr. W. Froude (M. Inst. C.E.), who, after a careful investigation of the instrument, summed up his remarks by saying: "The instrument is at once more convenient, more portable, and far less liable to injury and derangement than the ordinary aneroid; while its indications may be relied upon as confidently as those of the mercurial barometer."

Mr. Blackwell joined the Institution of Civil Engineers as an Associate in 1843, and was transferred to the class of Members in 1849, and whenever he could visit London he always attended the Meetings, to the interest of which he occasionally contributed.

Mr. WILLIAM CLEGRAM was born at Ryhope, in the county of Durham, on the 20th May, 1784, and commenced his career by going to sea, at the early age of 11 years, in a vessel belonging to his father, hailing from Sunderland. The snatches of education he was afterwards able to obtain, during his visits to Sunderland, were due to the kindness of Mr. Thomas Wilson, who was then superintending the construction of the iron bridge over the river Wear. His arithmetical and mathematical knowledge, and the love for engineering, which clung to him to the close of his life, he acquired from Mr. Wilson. He continued at sea until the year 1818; but during the leisure of a sea captain's life, he pursued the study of engineering and kindred subjects, and eventually he adopted engineering as a profession.

He projected and carried out, under the superintendence of the late Mr. William Chapman, C.E., the harbour at Shoreham, on the Sussex coast. He was then engaged, under the late Sir Samuel Brown, R.N., in the construction of the chain pier at Brighton, the suspension bridge at Hexham, and other similar works. He then

took charge of the Gloucester and Berkeley Canal, prior to its completion, in 1827, under the late Mr. Telford, and continued to be the resident Engineer of that work till within one year of his death, which occurred on the 20th October, 1863. For a large portion of his professional life he was, therefore, engaged on that navigation, as the superintendent as well as the engineer, and by arrangement with the Company, nearly the whole of his time was devoted to it alone. He was intimately acquainted with Mr. Chapman, Mr. Telford, Mr. James Walker, and Mr. (afterwards Sir W.) Cubitt, and he frequently met them from time to time in consultation, arbitration, &c., on a variety of works. He was consulted on many of the harbours of the South Coast, including Portsmouth, Littlehampton, Newhaven, Rye, and Folkestone, on all of which he reported. He was also employed by the Commissioners for the loan of Exchequer Bills to examine and report upon the harbours of Folkestone and Tralee.

He was a good practical astronomer, and he watched with much care the variation of the compass until it reached the limit of its westerly variation. He was devotedly attached to that branch of science, and in the last year of his life, when 79 years old, much of his time was occupied in various astronomical observations, and abstruse mathematical calculations upon them.

Mr. Clegram was elected a Member of the Institution of Civil Engineers on the 21st of February, 1832, on the nomination of his friend, Mr. Telford; but his constant residence in Gloucestershire prevented frequent attendance at the Meetings, though he ever took a lively interest in all that concerned the prosperity and well-being of the Society.

Mr. RICHARD CARDEN DESPARD was born on the 21st of May, 1831; he was the third son of the late Captain Despard, formerly of the 53rd Regiment, and subsequently for some years a Government Magistrate in the County Meath, Ireland. Deprived of a father's care at an early age, Mr. Despard was articled to Mr. John Coode (M. Inst. C. E.), and spent some years in his office, &c., and on the works of the Portland Breakwater. About the year 1851, he became assistant to Mr. Beardmore (M. Inst. C. E.), and eventually had charge of the construction of the Old Ford works on the river Lee,[1] of which he presented a description to the Institution, receiving for this communication a Council Premium of Books. He was also connected with the Colne Valley and the Halstead railways, as well as other undertakings; having been for some years prior to his decease the faithful

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xvii., p. 386.

and confidential coadjutor of Mr. Beardmore. From his acuteness as a mathematician, and clear workmanlike mode of dealing with the practical business of an Engineer, Mr. Despard won the confidence and esteem of all with whom he was brought in contact. In his private relations to a widowed mother and a numerous younger family, his character was a model; and those who were acquainted with his affectionate and generous disposition, can estimate the void caused by his almost sudden and early death, on the 19th of March, 1863, in the 32nd year of his age.

Mr. Despard was elected a Member of the Institution of Civil Engineers on the 4th of February, 1862; but for many years previously he had been a constant attendant at the meetings, and had taken advantage of the other facilities for professional advancement afforded by the Institution. On all occasions he never failed to acknowledge the great benefits that he had derived from access to the library, and from the privilege of being present at the meetings.

Mr. JAMES FENTON was born at Dunkenny, Forfarshire, on the 29th of August, 1815, and after serving an apprenticeship at the works of Messrs. James Cook and Co., Glasgow, as a mechanical Engineer, and under Mr. Blackadder (M. Inst. C.E.) as a Civil Engineer, he, in June, 1837, received an appointment under Mr. I. K. Brunel (M. Inst. C.E.), on the Great Western Railway, which was then in course of construction. In 1841, he became the resident Engineer and Locomotive Superintendent of the Manchester and Leeds line, where he remained for nearly five years, and on retiring he was presented by the workmen with a handsome silver vase and drinking-cup, and by the two engine-drivers on the Halifax branch with a silver snuff-box. In 1845, he undertook the position of Acting Engineer of the Leeds and Thirsk Railway, for which the Bill had just been obtained; but after remaining in the service of that Company for about eighteen months, and previous to the completion of the works, he entered into an arrangement with the proprietors of the Railway Foundry, at Leeds, then becoming known as builders of locomotive engines. Among the various works he executed while in that position may be specially mentioned the 'Jenny Lind' class of engine, designed with the view of combining simplicity of construction, with steadiness when running at high speeds. So highly were these engines thought of on some lines, that they were adopted as the type for all passenger engines, until by increase in the traffic heavier engines were required. Mr. Fenton also, whilst at the Railway Foundry, constructed and launched one of the largest landing-stages in the kingdom, that at New Holland, where the passengers by the Manchester and Sheffield Railway cross to Hull. On leaving the Railway Foundry

he was presented by the employés with a tea and coffee service in silver.

In 1851 he joined the Low Moor Company, as consulting Engineer, a position which he retained to his death; and there he had ample opportunity of meeting all the Engineers of reputation, and this soon brought him a large practice. As a witness he had considerable facility for explaining mechanical details in a popular manner. His last professional engagement was from the War Office, having been appointed to settle the question of compensation to the Elswick Ordnance Company. During the attendance on this business in London, he caught a severe cold, which hastened his end. He died at Leamington, where he had for some time resided for the benefit of his health, on the 22nd of April, 1863, at the early age of 47 years. His remains were conveyed to Low Moor, where they were interred on Monday, the 27th of April, and were followed to the grave by the principals and staff of the Low Moor Iron Company, together with a large number of the leading railway Engineers, and of his friends from various parts of the country. Mr. Fenton's loss will be much felt by many young Engineers, as he was always ready with his advice and assistance, and he was deservedly beloved and respected. Mr. Fenton was elected a Member of the Institution of Civil Engineers in 1849, and he contributed to the Proceedings a "Description of an Improved Form of Safety-Valve, for Steam Boilers."[1] He was one of the originators of the Institution of Mechanical Engineers, of Birmingham, in 1847, in the management of which he took a very active part, and he was for five or six years one of the Vice-Presidents of that Institution.

Mr. JOSHUA FIELD, F.R.S., was born at Hackney, in the year 1786. His father was largely engaged in the corn and seed trade, which he carried on in Lower Thames Street, where he had warehouses and a residence; but his family, which was large, chiefly resided at Hackney, then a village, quite separate from London. At seven years of age Joshua Field was sent to a boarding school at Harlow, in Essex, then conducted by the Rev. J. Brown, and he remained there until he was sixteen. He very early displayed a love for mechanical pursuits, collecting tools and learning to use them; and, as with most young mechanics, clocks and watches offered the readiest means of exercising this assumed vocation. The school clock being out of order, and Mr. Brown having heard of his pupil's skill on the watches of some of the neighbouring farmers, asked if he thought he could mend it, and on permission being given him to try, he made so

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xv., p. 33.

good a job of it, that his reputation became great amongst his fellow pupils.

On leaving school in 1802, he visited, as often as he could, the steam-engines and mills to be found in London at that time; and the natural bent of his mind no doubt became strengthened and confirmed by what he saw on these occasions, and which led him to desire most earnestly to be engaged in such pursuits. About this time the Government commenced the establishment of machinery in the Royal Dockyards. This was effected under the superintendence of the late General Sir Samuel Bentham, who, with a staff under him, began his operations in Portsmouth Yard. It was thought by his friends that an opportunity might there present itself for testing his mechanical inclination, and the father of young Field having applied to Sir Samuel Bentham, the son was admitted into the works at Portsmouth, where he remained about two years, under Mr. Simon Goodrich (M. Inst. C.E.), then chief Mechanical Superintendent, and Mr. Linahan, the Master Millwright, under whom he was chiefly engaged in drawing, but occasionally working with the millwrights. After remaining some time at Portsmouth Yard, Mr. Field was requested by Sir Samuel Bentham to come up to the Admiralty at Whitehall, to assist in the drawing department, and there he remained about a year. About that time the block machinery invented by Mr. (afterwards Sir Isambard) Brunel was being constructed by Mr. Maudslay, who, requiring some assistance in drawing, applied to Sir Samuel Bentham to recommend him a competent draughtsman, when Sir Samuel and Mr. Goodrich strongly recommended young Mr. Field. This accidental circumstance was the origin of the subsequent connexion of Mr. Maudslay and Mr. Field, in which their combined talents produced for the country many important improvements in marine engineering. An intimacy was also commenced with the late Mr. I. K. Brunel, which continued, without interruption, until the death of that gentleman. Mr. Field's new engagement with Mr. Maudslay commenced some time in 1804, at the establishment in Margaret Street, Cavendish Square, where there were employed about eighty men, who were chiefly engaged upon some of the best work of the period, requiring the use of the most perfect tools, and thus the attention of Mr. Maudslay was devoted to maturing improvements in them. At this period Mr. Maudslay's was about the only factory in which the slide rest was generally applied to the lathe. In 1810 the manufactory was removed to Lambeth, where a variety of mechanical operations were carried on. Steam Navigation was practically introduced in England about 1812, and the manufacture of marine engines was commenced by Mr. Maudslay, and has since been the principal, although by no

means the sole, employment of the establishment thus founded. For besides saw machinery, corn mills, block and mint machinery, in all of which much has been done there, Mr. Maudslay made the first shield used in the construction of the Thames Tunnel. But steam-engines, for land and marine purposes, have been what may be termed the staple trade of the works; and for the purposes of navigation alone this firm had made, up to Midsummer, 1863, engines of the aggregate nominal power of 90,790 horses. Paddle and screw engines made by Messrs. Maudslay, Sons, and Field, are to be found in operation in all parts of the world, as well in the naval marine of this and other countries, as in mail steamers and mercantile vessels.

The 'Enterprize' steamer, commenced by a private Company—of which Mr. Maudslay was one of the principal shareholders—first made the passage to Calcutta, and proved a good pioneer for more recent operations. Subsequently the 'Great Western,' between Bristol and New York, may be said to have given birth to the present constant steam communication between the mother country and America. To the design and construction of the engines of the 'Great Western,' Mr. Field early and late gave most particular attention. The regular navigation of the Atlantic by steam was then regarded as an experiment on a large scale, and many scientific men agreed with the late Dr. Dionysius Lardner in prognosticating failure. The 'Great Western,' however, proved a complete success, and it is believed that no engines ever went through such continuous and arduous work more satisfactorily, or with less expense in repairs. This vessel eventually passed into the hands of the West India Mail Company, and continued until a recent period to do good service. It should be remembered that these were the days of flue boilers and moderate pressure; but if engines and boilers on this principle lacked somewhat of speed, when compared with the results of more recent times, they undoubtedly had the advantage of a smaller consumption of coals, and of greater durability.

In 1822 Mr. Field was, with Mr. Maudslay's eldest son, admitted as a partner. On the 14th February, 1831, Mr. Maudslay died, and the works were greatly extended, so as to meet the expanding character of steam navigation.

Mr. Field, in conjunction with Mr. Lloyd, Mr. Penn, Mr. Appold, and Mr. Amos, was also consulted in reference to the laying of the Atlantic Telegraph Cable; and it was under their advice that the machinery was constructed by which the cable was actually laid in the first expedition, though the undertaking was not, unfortunately, equally successful in other respects. He was likewise called upon for his advice on many occasions by the Astronomer-Royal, and the time balls at Greenwich, at the South Foreland, at

Liverpool, and at Edinburgh, were made by the firm of which he was a partner.

Mr. Field was one of the founders of the Institution of Civil Engineers, the origin of which was very humble. About the year 1816, Mr. Henry Robinson Palmer, who was then a pupil of the late Mr. Bryan Donkin, suggested to Mr. Field the idea of forming a society of young Engineers, for their mutual improvement in mechanical and engineering science; and the earliest members were Mr. Henry Robinson Palmer, Mr. William Nicholson Maudslay, and Mr. Joshua Field. To these three were shortly added Mr. James Jones, Mr. Charles Collinge, and Mr. James Ashwell. They met occasionally in a room hired for the purpose, and to them were soon attracted others having the same objects in view. Mr. Field was the first Chairman of the Institution, being elected to that post on the 6th of January, 1818. Subsequently he became, in 1837, a Vice-President, an office he filled until he was elected President in 1848 and in 1849, and he continued to the last to be an active member and warm supporter of the Institution; constant in his attendance at the Meetings, and taking part in the discussions, and if not personally contributing Papers, procuring them from Members having more leisure.

It is to be regretted that, from a modesty that was in every way natural to him, many of the incidents of his early career are either not known, or only partially given. He was often pressed to note down some of his early recollections, as well concerning himself as of those with whom he was brought into contact; but it was only lately that he in part complied with the representation made to him. It was once remarked, by Lord Brougham, of an intimate friend of his, that those who knew him only in his external relation to society knew but half his worth, and the same may with equal confidence be said of Mr. Field. Unassuming to a degree in his personal demeanour, he was the embodiment of all that was courteous, considerate, and kind in his feelings towards others; and, indeed, he naturally presented so much of the true gentleman and benevolent kind-hearted man, that it was impossible to make his acquaintance without entertaining for him the highest sentiments of respect and esteem. It was a privilege to spend a social hour with him, when he would bring forth vast stores of information bearing directly or collaterally on his varied experience of men, and of mechanical and scientific pursuits, and the natural geniality of his nature then showed itself most conspicuously. Possessing an admirably balanced mind, he was never either unduly excited or depressed. His advice was often sought, even by strangers, and no effort wearied him in his endeavours to correct their views when wrong, or to confirm them when right; whilst to all appeals of a charitable nature, the hand of benevolence was constantly open,

and he seemed to feel a pleasure in materially aiding those that needed help. His charity was liberal, without a particle of ostentation, and discriminate, without a tinge of selfishness. In religious belief Mr. Field was a Nonconformist, but of such enlarged Christian views, that he frequently contributed to churches and schools in connexion with the Establishment. Few, indeed, were the cases of private or public want brought under his notice that he did not readily, and often liberally, respond to; and as a short summary of his character, it may be said, that he was a truly good man in private life and a great man in his professional career.

Mr. JOSEPH GLYNN, F.R.S., was a native of the North of England, whence have proceeded so many men eminent in mechanical and engineering pursuits. He was the son of Mr. James Glynn, of the Ouseburn Iron Foundry, Newcastle-upon-Tyne, and was born in Hanover Square, in that town, on the 6th of February, 1799. To Mr. John Bruce, of the Percy Street Academy—himself a mathematician of considerable attainments, who taught the rudiments of mathematics to the late Robert Stephenson, and who turned out many pupils attaining eminence in many walks of life—is due the credit of the intellectual training which afterwards enabled Mr. Glynn to apply to useful purpose the mechanical talents which seemed to be innate rather than to have been acquired by after education. Mr. Glynn's career was nearly cut short in early life, by an accident which exercised much influence in turning his mind in a direction where it was afterwards most actively employed. His father was also a shipowner; and in a schoolboy visit to one of his father's ships, Joseph, with two of his brothers, was severely burned, and otherwise injured, by an explosion of gunpowder. He made several voyages to sea to recover his health, and thus acquired a knowledge of seamanship and of the construction and qualities of sea-going ships, which he afterwards turned to good account. He continued at the Ouseburn Foundry, as his father's assistant, until the year 1820, when he executed his first engineering work, which was the erection of a steam-engine for the Earl of Carlisle, to drain the Talkin Colliery, near Brampton, Cumberland. He was assisted in the execution of the work by two young mechanics, then workmen, who have both since attained great eminence, the late Sir Peter Fairbairn and Mr. Robert Hawthorn (M. Inst. C.E.) In the following year, 1821, the introduction of coal gas having rendered the inhabitants of Berwick-upon-Tweed discontented with the old system of lighting, Mr. Glynn was called in to design and execute the gas works for that borough, and from 1821 to 1859 the establishment served its original purpose without altera-

tion. The success of the Berwick Gas Works was so complete, that he was applied to soon afterwards by the inhabitants of Aberdeen to design gas works for that city, and he furnished reports and plans, though his other engagements prevented him from superintending their execution—he having, in the interim, become Engineer to the Butterley Iron Company, Derbyshire.

From that time Mr. Glynn's individual reputation almost merged into that of the Butterley Company, with which for more than a quarter of a century he was intimately connected. At that period the marine steam-engine, though a sturdy infant, gave little promise of the giant stature to which it has since grown. Steam vessels, which have since been eclipsed by the later achievements of science, industry, and skill, were then new and hazardous experiments, requiring boldness to undertake and sagacity to plan. Steam navigation was represented by a few Thames steam-boats, gradually but successfully competing with sailing ships and barges, and ocean navigation by steam, though it had been attempted, had not extended widely; stationary engines of small power were employed in drawing to the surface of the earth its buried treasures, from depths which were then thought formidable, but which are now insignificant. The dimensions of these Mr. Glynn gradually increased until they reached 200 H.P. The locomotive was struggling into being, through the efforts of Trevithick and Brunton, and was being matured in the brain of George Stephenson. In his visits to Killingworth, with his schoolfellow, Robert Stephenson, young Glynn "sat at the feet of Gamaliel," and the seed sown in these interviews afterwards ripened into works of solid practical utility. The Butterley Company undertook and executed works, of whose merit it will never be known how much was due to their Engineer, and how much to them as contractors. Following the example of the late Mr. John Rennie, to whom is due the merit of the great introduction of cast iron into structures, and who drew his supplies chiefly from the Horseley Iron Works, then belonging to the late Mr. Aaron Manby, the great Engineers of that day found useful auxiliaries, in the extensive resources of the Butterley Iron Works. Sir John Rennie (Past President Inst. C.E.) was at that time employed by the Government to complete the Royal Naval Establishment at Sheerness, and Sir Edward Banks undertook the works as contractor for a sum of nearly one million sterling. A great part of the ironwork for this extensive contract was executed at Butterley. The same engineer and contractor undertook the building of the new London Bridge, and the steam machinery for keeping out the water, while the works proceeded, was supplied from the same source, which had already furnished the ironwork of Vauxhall Bridge, over the

river Thames, erected from the designs of the late Mr. James Walker (Past President Inst. C.E.); for at that time large ironworks, capable of executing extensive contracts, were few, and the great industrial establishments which have since sprung up for the manufacture of machinery had no existence.

The General Steam Navigation Company, after a severe struggle, in which Sir Edward Banks and his partner, Mr. William Jolliffe, took an active part, finally succeeded in establishing their merchant navy; and though they have since been surpassed by larger and more powerful bodies, supported by the public purse, they were the pioneers of this new arm of civilization. The 'George IV.' and the 'Duke of York,' made their first voyages to Lisbon in 1826, with great success. The late Mr. Joseph Miller (M. Inst. C.E.), afterwards the partner of the late Mr. Barnes (M. Inst. C.E.), and the head of the well-known firm of Messrs. Miller, Ravenhill, and Salkeld, who was Mr. Glynn's predecessor at Butterley, had previously built some very good marine engines, and had commenced those of the 'Lord Melville,' which were completed by Mr. Glynn; this vessel was followed by the 'Earl of Liverpool,' the 'Attwood,' the 'Sir Edward Banks,' the 'City of London,' the 'Royal Sovereign,' the 'Brocklebank,' and the 'Ramona,' for all of which the engines were designed by Mr. Glynn. The Gainsborough and Hull packet, and the 'Trent,' plying on the Humber, were also the precursors of a system of river navigation by steam for the conveyance of merchandize, which the 'Rob Roy,' with engines designed by him, carried to Hamburgh.

The engineering skill of Mr. Glynn was also called in from time to time to repair and reconstruct several steam vessels built elsewhere. The 'Victoria,' of which the boilers twice exploded, killing nine men on the former and six on the latter occasion, was rendered a seaworthy vessel by his alterations. The 'Harlequin,' the 'Columbine,' the 'Superb,' the 'Hilton Jolliffe,' the 'Rapid,' the 'Talbot,' the 'Belfast,' the 'William Jolliffe,' and the 'Mountaineer,' all passed under his hands, and were altered and made effective by the Butterley Company. The 'Firefly,' and the 'Firebrand,' for the English navy, and the 'Jason,' and the 'Colchis,' for the Russian Government, were fitted with engines from his designs, as were the 'Nicholas I.' and the 'Alexandra,' the first steamers from Lubeck to St. Petersburg under the Russian flag. The Butterley Company also fitted out steam dredging vessels, for the State of Lubeck, for the Hanoverian Government, and others. The iron roofs, mills, and heavy machinery, which were executed from Mr. Glynn's designs, and which were despatched from Butterley to all parts of Europe, to the colonies, the East and West Indies, and the continent of America, bore testimony to his industry, as well as to the fertility

of his invention, though his modest labours seldom came before the world. About this time he sent out to Spain a complete iron work, executed for Don Manuel Heredia, of Malaga, which subsequently became the parent of many others. The number of powerful steam-engines made at Butterley for mining purposes was very considerable ; one of these, a winding engine, was erected at Leasingthorne Colliery, near Ferry-hill, for the Durham County Coal Company. Mr. Glynn was an advocate for the use of water as a moving power, and he erected some water-wheels of large dimensions. His name, however, will be chiefly associated with the employment of the water-wheel or scoop-wheel, as it is called, for draining marshes and fens by steam power. A water-wheel driven the reverse way by a steam-engine, where the object is to lift a large quantity a short distance, has been found in many localities superior to any system of pumps ; and this plan was used by Mr. Glynn with great success in the fen country in England, and also in Hanover and Holland, a 'polder' near Rotterdam having been thus drained. He was in correspondence with his late Majesty the King of the Netherlands, concerning the application of this system to the Lake of Haarlem, when the abdication of his Majesty transferred the execution of the project to other hands, and it has since been successfully carried into effect by pumping engines, erected from the designs and under the direction of the late Mr. Joseph Gibbs (M. Inst. C.E.), and Mr. Dean. Mr. Glynn also drained by steam power the following districts, amounting to many thousand acres :—Deeping Fen, near Spalding, Lincolnshire ; Misterton Soss, with Everton and Grindley Cars ; Littleport Fen, near Ely, Cambridgeshire ; Magdalen Fen, near Lynn, Norfolk ; Middle Soham Fen, Cambridgeshire ; Soham Mere, Cambridgeshire ; Sutton and Mepal, near Lynn, Norfolk, altered by him in 1861 ; Waterbeach Level, Cambridgeshire ; March District ; March West Fen, Cambridgeshire ; the Bennimoor District, Mildenhall, Suffolk ; and Lakenheath, Suffolk. For all these works the Butterley Company manufactured the engines from his drawings. Also for the Hammerbrook drainage, near Hamburgh, of which Mr. Lindley (M. Inst. C. E.), was the Engineer, under the Hamburgh Government.

Mr. Glynn likewise executed some drainage works by steam power in the colonies, one of which, fulfilling a double purpose, was erected in British Guiana ; drainage in the wet season being combined with irrigation in the dry season. His drainage works in the counties of Cambridge, Norfolk, Suffolk, Lincoln, and York were extensive and successful. Mr. Glynn also designed and constructed, from his own designs and those of other engineers, many iron bridges, among which may be mentioned Haddlesey bridge, between Doncaster and Selby ; for the Dean and Chapter of Ely Cathedral,

an iron bridge at Ely; that across the Cam at Gerrard's Hostel, Cambridge, from designs by the late Mr. Mylne (M. Inst. C.E.), after the celebrated bridge (Ponte della Trinita) at Florence; also, from the designs of the late Mr. Walker (M. Inst. C.E.), the lifting bridge at Selby, on the line of the Hull and Selby Railway.

In an age when the construction of railways frequently amounted to a mania, and the desire to extend them gave rise to speculations of the wildest and most unprofitable character, Mr. Glynn could not be expected to remain a silent and unconcerned spectator of the rapid development of steam communication by land. He was concerned with Mr. Jessop in setting out the Midland Counties Railway, and took an active interest in its affairs, with the working of which in the neighbourhood of Derby he was well acquainted. He was a member of the committee by whom the purchase of the Great North of England Railway was negotiated for what is now called the North Eastern Railway Company. He was the Secretary of the Committee of Investigation into the affairs of the Eastern Counties Railway, and when, in consequence of the report of that Committee, Mr. Hudson and Mr. Waddington resigned, and Mr. E. L. Betts (Assoc. Inst. C.E.), was appointed chairman, Mr. Glynn was elected deputy-chairman of that company. On the retirement of Mr. Betts, shortly after, from the active duties of the board, in consequence of an accident which threatened to deprive him of sight, Mr. Glynn filled the office of chairman for two years.

Mr. Glynn was elected a Member of the Institution of Civil Engineers on the 22nd of April, 1828, and he contributed several Papers to the Meetings; among those which excited peculiar interest may be mentioned the following:—On the 22nd of June, 1847, "A Review of the Plans which have been proposed for connecting the Atlantic and the Pacific Oceans, by a Navigable Canal."[1] The Emperor of the French, then Prince Louis Napoleon, having written on the subject, was invited to be present at the reading of the Paper, and to take part in the discussion, when he made an excellent speech, which is recorded in the Minutes of Proceedings. Also, on the 20th of May, 1851, "On the Isthmus of Suez and the Canals of Egypt,"[2] which drew from the late Mr. Robert Stephenson a very interesting account of his travels in Egypt, and his views with respect to the projected canal of the Isthmus of Suez. For the former of these communications a Telford Medal was awarded, and for the latter a Council Premium of Books—marks of distinction which were very highly prized by

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. vi., p. 399.
[2] *Ibid.* vol. x., p. 369.

Mr. Glynn. He had previously contributed several other useful Papers,[1] which are published in the Minutes of Proceedings, and he frequently took part in the discussions.

The Gold Isis Medal of the Society of Arts was voted to Mr. Glynn for a communication dated 8th February, 1836, on his application of Steam Power to Draining Fens.[2] This Paper was republished in French; it was also translated into German, by Herr Blohm, Engineer of the Hanoverian Government, and was published in Hanover, and at Mecklenburg; it was likewise translated into Dutch, and published in Holland. Descriptions of cranes for the Royal Dockyard at Woolwich were contributed by Mr. Glynn to the Professional Papers of the Corps of Royal Engineers,[3] as well as other useful and valuable writings. The want of similar publications which he had experienced in his youth had made him feel the shortcomings of many scientific works, and his object in writing was rather to produce a handbook for the daily use of the mechanic and the artizan, than an elaborate treatise of little practical use.

He contributed to Mr. Weale's Rudimentary Series "A Treatise on Cranes," of which work 30,000 copies have been sold, and it has been translated into nearly every European tongue. His "Treatise on the Power of Water" has met with nearly equal success, and has put within the reach of the practical millwright and the mechanical engineer, the information which a few years since was confined to the abstract mathematician.

On the 16th November, 1836, Mr. Glynn was elected a Member of the Society of Arts, and subsequently a Member of the Council, and a Vice-President. He was at the same time elected an Honorary Member of the Literary and Philosophical Society of Newcastle-upon-Tyne, being the only person upon whom the Society had ever conferred this privilege. On the 8th February, 1838, he was elected a Fellow of the Royal Society.

The opinion of Mr. Glynn, as a sound practical man, was much valued by the profession, and his evidence was sought in many cases of disputed patents; his judgment in the arbitration and settlement of disputes where mechanical matters were concerned was highly esteemed. He was examined before the Royal Commission on the use of iron for railway structures, and reported on the overland route to India, and the competing scheme of the

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[1] These are—"Description of a Sawing Machine for cutting off Railway Bars," read March 26, 1839; "On the Use of Mica, as a substitute for Glass, in the Windows of Workshops," read March 31, 1840; and "On the Causes of the Fractures of the Axles of Railway Carriages," read April 23, 1844.

[2] *Vide* Transactions of the Society of Arts, &c., vol. li.

[3] *Vide* "Papers on Subjects connected with the duties of the Corps of Royal Engineers," vol. iv., p. 221, and vol. v., p. 194.

Euphrates Valley, and gave evidence before committees of the Lords and Commons on various railway and other projects.

He died in London, on the 6th of February, 1863, aged 64, having gained the confidence of his professional brethren, and the warm esteem of a large circle of private friends.

Mr. MARK JONES was elected a Member of the Institution of Civil Engineers on the 4th of December, 1849. Previous to that date he had, according to the statement of qualifications inserted in the form of application for admission into the Institution, "after serving a regular period of pupilage as a mechanical engineer, entered the service of the Honourable East India Company, and for sixteen years was the Chief Superintending Engineer of the Government Steam Foundry, Calcutta." His death occurred at Oldbury, near Birmingham, early in the year 1863, when in the 59th year of his age; but it has not been possible to obtain any other particulars.

Captain WILLIAM SCARTH MOORSOM, the third son of the late Sir Robert Moorsom, was born, in the year 1804, at Upper Stakesby, the residence of his father, near Whitby, in Yorkshire. Being intended for the army, young Moorsom entered the Royal Military College, at Sandhurst, in 1819, and quickly rose to a high position among the cadets of that establishment, chiefly in consequence of his attainments in fortification and military surveying. On the 14th of June, 1822, he was presented with a sword by the gentlemen cadets of his (C) Company, "as a token of their sincere regard and esteem." After passing examinations in double courses of the highest classes, he joined, in the following year, the 79th Regiment, then stationed in Ireland; and, while pursuing the ordinary duties of the garrison in Dublin, he found time make a trigonometrical survey of the whole of that city and neighbourhood, extending over an area of about 150 square miles. This survey was the one used in the Quartermaster-General's office, at the Horse Guards, until it was superseded by the large Ordnance Survey of Ireland. Having, through this work, been brought under the notice of the Adjutant-General (Sir H. Torrens), a lieutenancy, by purchase, in the 7th Fusileers, was soon offered to him. Shortly after he joined that regiment, he was ordered to the Mediterranean, and four companies were formed into a reserve, the adjutancy of which was given to Lieutenant Moorsom. On the promotion of its Colonel, Sir Edward Blakeney, to be Major-General, the 7th Fusileers were placed under the command of Lord Frederick Fitz-Clarence, who, upon Lieutenant Moorsom quitting the regiment on promotion to an unattached company,

issued a regimental order highly complimentary of his services as adjutant. Captain Moorsom was almost immediately brought on full pay in the 69th Regiment, and within a few weeks exchanged into the 52nd Light Infantry, then stationed in Nova Scotia. There his industry was again conspicuous by his exploration of the province, which became better known to the public by his publication of "Letters from Nova Scotia," in 1828. His survey of the harbour and environs of Halifax still remains in the Quarter-master-General's office, at the Horse Guards, as the best plan to which reference is made for that locality. His well-known ability in this branch, and his local knowledge, led to his appointment, by Major-General Sir Peregrine Maitland, to be Deputy Quarter-master-General to the division, upon the retirement of Lieutenant-Colonel Beresford, until a successor to that office should come out from England. Captain Moorsom's ability again displayed itself in this capacity, by the office being soon supplied with routes and copious notes of the capability for supply and maintenance of troops, over every part of the provinces of Nova Scotia and New Brunswick. For this information, and for the general state of efficiency in which the department was placed, he received a complimentary letter of thanks from his successor, Lieutenant-Colonel Broke.

On returning to England it was found desirable, from domestic circumstances, that Captain Moorsom should reside with his father, and finding that promotion to an unattached majority by purchase was denied him, notwithstanding that he had been selected by the General commanding his division to fill a post involving the duties of Lieutenant-Colonel, he quitted the army and resided with his father until the death of the latter in 1834. The previous year had witnessed the incorporation, by Act of Parliament, of the London and Birmingham Railway Company, of which his brother, the late Admiral Moorsom, was then secretary, and with whom he was associated in promoting the early stages of that great undertaking. The residence of Sir Robert Moorsom was situated very near this line of railway, in one of the most difficult portions, and the survey by Captain Moorsom of a section across the valley of the Ouse, by which the original line might be straightened, and a large amount of embankment dispensed with, attracted the attention of the late Mr. Robert Stephenson, then chief engineer of the railway, who kindly gave Captain Moorsom every facility for making himself master of the practical details of that great work.

During the years 1835 and 1836, Captain Moorsom visited almost every railway and canal work of importance then going on in England, thus making himself acquainted with the different methods pursued in the execution of such works during their daily progress, and in the management of those that had been recently

finished. Thus, in the autumn of 1836, when applied to by the Messrs. Sturge, of Birmingham, to undertake a survey of the country between Birmingham and Gloucester, in order to connect those towns by railway, he felt enabled to meet the difficulties of the task, by the experience which such extensive inquiries and observations had given. This work severely tested the judgment and skill of the Engineer, inasmuch as the great table lands of Staffordshire were to be ascended from one of the lowest valleys of England—that of the Severn. To accomplish this, the severest inclined plane, then known in the world, was proposed by Captain Moorsom to form part of his line; the table land being ascended in one continuous plane, rising upwards of 300 feet in little more than two miles, or at the rate of 1 in 37. An opposition to this plan was brought forward by Mr. George Stephenson, then in the zenith of his reputation, who proposed to avoid the incline of the Lickey by a detour of seven miles. Mr. I. K. Brunel (M. Inst. C.E.) had also proposed to avoid the same incline by a detour of three miles; but the opposition was negatived in Parliament, and Captain Moorsom's original plans were carried out. The experience acquired by Captain Moorsom in his numerous military surveys did him good service on this his *début* in civil practice, for the country was so thoroughly examined between Birmingham and Gloucester, and the general line for the railway so carefully selected, that no competing line has ever been projected to interfere with it. The completion of the Birmingham and Gloucester Railway, at the same cost per mile as the Grand Junction Railway, by Mr. Joseph Locke (M. Inst. C.E.), was conclusive evidence of the careful control over the expenditure exercised by the Engineer; but although completed, the work was not yet concluded. To work the incline of the Lickey, thus rising for two miles at the rate of nearly an inch in a yard, was a subject of no small anxiety, seeing that all the trade between the Midland and the Western counties of England would pass over it. After visiting the various inclines then at work, chiefly in the coal districts, with trains of minerals, without passengers, Captain Moorsom decided to recommend that the Lickey should be worked by locomotive engines. The Directors at the Birmingham board were alarmed at the idea of doing that which had no precedent, and advertised for tenders to erect stationary engines to work the incline. Fortunately, the heavy amounts of the tenders again frightened them, and (always backed by the Deputy Chairman, Mr. Samuel Baker, then of Higham Court, near Gloucester), Captain Moorsom was allowed to go on with his plans. But then arose the question, who was to make the locomotive which should drag a passenger train, at the rate of twenty or even of fifteen miles an hour, up two miles of an incline of 1 in 37? Upon applying to the first makers of the day, Messrs. Robert Stephenson

and Co., of Newcastle-on-Tyne, Mr. Bury, of Liverpool, and others, every one declined the task. In this dilemma, Captain Moorsom conferred with Mr. Norris, of Philadelphia, with the performance of whose engines upon American railways he had become acquainted, and, again backed in his efforts by the firmness of Mr. Baker, he procured a small locomotive engine of Mr. Norris's manufacture, and practically demonstrated the feasibility of working the Lickey by that class of engine.[1] It may surprise those who are accustomed to the present system of locomotives to learn, that the first engine which took a train up the Lickey incline had cylinders of only 10½ inches diameter, with a length of stroke of 18 inches, and with driving wheels 4 feet diameter, the engine, when in working order, weighing rather less than 10 tons. The practical working by this system, thus established has never been disturbed, and the Lickey continues to hold its place in the first rank of inclined planes worked by locomotive engines.

The mode of constructing the foundations of an iron viaduct of three arches, crossing the river Avon, near Tewkesbury, on this railway, was brought before the notice of the Institution of Civil Engineers,[2] and the "Telford Medal" was awarded to Captain Moorsom for the first practical example of iron caissons sunk into the bed of the river by their own weight, thus forming a chamber, from which, by the aid of powerful pumps, the water was cleared out, and the iron casing when sunk down to a solid bed, was afterwards filled with concrete and masonry to support the superstructure.

Captain Moorsom's success led to his being employed by the Cornish committee, of which the Earl of Falmouth was chairman, to lay out their lines from Exeter and Plymouth to Falmouth, upon which a full report was printed and published in 1841. The line of the West Cornwall Railway, from Truro to Penzance, was also laid out by Captain Moorsom about the same period.

The railway fever of 1844-5 called into requisition the services of Captain Moorsom to lay out several extensive systems of railway, viz.:—The Shropshire system, from Birmingham to Wolverhampton, Shrewsbury, Newton, and Chester, nearly 100 miles; the Yarmouth Junction, from Diss and Beccles, 50 miles; the Irish Great Western, from Naas, by Tullamore, to Galway, 120 miles; the Metropolitan Counties Junction, from Gravesend, by Reigate, Dorking, Weybridge, Staines, Rickmansworth, St. Albans, Chelmsford, and Billericay to Tilbury, 120 miles; the London, Hammersmith, Staines, and Windsor, 25 miles, and several smaller lines; and of these the Southampton and Dorchester, and the Waterford and

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. i. (1840), p. 45; and vol. ii. (1843), p. 99.

[2] *Ibid.*, vol. iii., p. 60.

Kilkenny were executed, the former wholly, and the latter principally, by him.

The Southampton and Dorchester Railway has been made the subject of a contest which has clearly proved the sound judgment with which that line was laid out and constructed as a commercial undertaking. The principle adopted was to approach every town on the line, throughout this agricultural district, so closely as to secure the short local trade as well as the "through traffic," and by laying out what its adversaries have facetiously called a "corkscrew" line. Captain Moorsom attained this object in a manner so complete that not even a van, and hardly a carrier's cart, now runs on the adjacent roads, owing to the better accommodation afforded by the railway. Subsequently his efforts were directed to establish a south-west coast line of railway, in extension of the Southampton and Dorchester Railway, from Dorchester through Bridport, Axminster, and Honiton, to Exeter; but the South Western Railway Company eventually procured the incorporation of the rival line through Yeovil.

The Waterford and Kilkenny Railway[1] presents only two features of interest, one being a station at Kilkenny, laid out to accommodate the interchange of four different lines of traffic from Dublin, Waterford, Wexford, and Cashel; and the other a viaduct over the River Nore,[2] 85 feet in height and of 200 feet span, constructed in timber, on the lattice principle, the abutments being built of limestone. The cost of the whole was under £10,000, and the work was the largest of the kind in the three kingdoms at the time of its erection.

In 1850, the Prussian Government issued proposals to the engineers and architects of all nations, to send to Berlin designs for a great bridge to be erected over the Rhine, at Cologne. This bridge was required to give passage to a railway, a carriage-road, and foot-passengers. The most celebrated Engineers of Europe and America sent in designs to the number of sixty-one, and among them was one by Captain Moorsom, to which the Prussian Government awarded the Engineering Prize, while the Architectural Prize for the same work was carried off by Mr. Swedler, an architect of Berlin. Captain Moorsom's design embraced spans of 600 feet, in wrought iron, while the piers and abutments were so arranged as to form casemated batteries for the protection of the town from an advance up the river.

The temporary cessation of the great railway undertakings in the three kingdoms about this period—1852 to 1856—was felt by Captain Moorsom, in common with many others of his professional

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. viii., p. 287.
[2] *Ibid.*, vol. xi., p. 426.

brethren. His attention was then directed to projects for extracting gold from the ores of Great Britain. His reports to the Britannia and Poltimore Mining Companies, in 1852, fairly brought the subject, for the first time, in a practical shape, on a large scale, before the public. The machinery erected by those companies, under his direction, was so far successful as to produce gold from the ores; but the quantities were not sufficient to pay for the cost of production, and the undertakings were abandoned—perhaps somewhat hastily, as in other quarters of Great Britain success has attended perseverance.

In the winter of 1856, Captain Moorsom was selected by the Colonial Minister, Mr. Labouchere, to visit Ceylon on behalf of the Government, in order to determine whether a railway could be profitably constructed between Colombo, the principal port, and Kandy, the ancient capital of that island, and the centre of a very productive district for the growth of coffee. Receiving his instructions on the 24th December, and pressed by the Colonial Office to complete his work before the ensuing rainy season in May should oblige a cessation of operations, Captain Moorsom sent off his first division of surveyors early in January, a second division on the 20th of that month, and followed himself on the 4th February, 1857. On the 12th May, Captain Moorsom presented his report[1] to the Governor of Ceylon, and received the thanks of that functionary, afterwards confirmed in gratifying terms by letter of the Colonial Minister, dated the 23rd of July, 1857.

Captain Moorsom was elected an Associate of the Institution of Civil Engineers, on the 24th of March, 1835, and was transferred to the class of Members on the 20th of February, 1849. He became a Member of the Society of Arts on the 31st of January, 1843. He presented several Original Communications to the Institution;[2] and there were many subjects connected with Civil and Military Engineering, upon which he frequently spoke at the Meetings; and it has been observed that he not only spoke well, but always to the point, and was invariably listened to with

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[1] This Report has been published in "Professional Papers of the Corps of Royal Engineers," vol. vii. (new series), p. 8.

[2] The dates when these Papers were read, and their titles, are as under:—

April 7, 1840.—"Account of a series of Experiments with Locomotive Engines, manufactured by Mr. Norris, of Philadelphia, U.S."

February 28, 1843.—"Description of the 'Philadelphia' Engine, manufactured by Mr. Norris."

January 9, 1844.—"Description of a Cast-Iron Bridge over the River Avon at Tewkesbury, on the Birmingham and Gloucester Railway."

January 12, 1849.—"Observations on the Working of the Inclined Planes on the Waterford and Kilkenny Railway."

April 13, 1852.—"Description of the Lattice Timber Viaduct erected on the River Nore, on the Waterford and Kilkenny Railway."

attention. He never shrank from speaking even an unpleasant truth, yet those who knew him bear testimony to his extremely courteous manner.

Concerning the social character of Captain Moorsom, it may be said that his life was one of constant energy and activity, both of mind and body. Habitually an early riser, his day began while the world still slept; nor did office hours close his daily labour. As in all his public actions integrity and honour were the most visible features, so those who witnessed his more private career could not fail to observe in him all the attributes of a true and earnest Christian gentleman. This it was that supported him through much domestic affliction; this it was that taught him to bear with patient resignation a long and painful illness; and this it was that, at the last, enabled him to meet death calmly and undismayed.

Captain Moorsom died in London, on the 3rd of June, 1863, in the 61st year of his age, leaving a large family, of whom one only has adopted his father's late profession, and four others are emulating the military career of their eldest brother, who fell at Lucknow in 1858.

Mr. BERIAH BOTFIELD, M.P., M.A., F.R.S., &c., was descended from the ancient Shropshire family of Botevyle, a branch of which had settled at Hopton Court and Decker Hill, Salop. He was the eldest son of Mr. Beriah Botfield of Norton Hall, Northampton, where the son was born on the 5th of March, 1807. He received his education at Harrow, and through life took every opportunity of showing his attachment to his early school, to the library of which he made munificent contributions, and he established a Medal there in 1853. He was entered at Christ Church, Oxford, and graduated as B.A. in 1828, and M.A. in 1847.

He was returned to Parliament for Ludlow, in the Conservative interest, in 1837, and with short intermissions he continued to represent that borough until the period of his decease. He was also a Deputy Lieutenant for Northamptonshire and Shropshire, and was Sheriff for the former county in 1831. His scholastic and literary attainments were of a high order, and they were recognised abroad by his nomination as a Chevalier of the Saxon Order of Albert the Brave, and of the Belgian Order of Leopold. He was the Secretary of the Roxburghe Club, for which position his antiquarian knowledge eminently fitted him. He was a Fellow of the Royal Society and of the Society of Antiquaries, and was a Member of several other learned and scientific bodies. He was a frequent contributor to the periodical scientific literature of the day,

and the author of several well-known works, among which may be mentioned various tracts upon bibliography, communicated to the Philobiblion Society; Prefaces to the first editions of the Greek and Roman Classics, and of the Sacred Scriptures; Stemmata Botevilliana; Expenses of England in the 13th and 14th Centuries; and Notes on the Cathedral Libraries of England.

He joined the Institution of Civil Engineers as an Associate May 5th, 1840, and frequently attended the meetings, taking great interest in the discussions, more especially in those connected with the iron manufacture, with which he was connected in Staffordshire and Shropshire. At his decease, which occurred at his residence in London, on the 7th of August, 1863, in his fifty-eighth year, he left a bequest to the Institution of Civil Engineers, to whose library he had previously been a liberal contributor.

He was a man of distinguished manners, great kindness and urbanity, and had not only the will but the means to confer benefits where timely aid was needed, and he rarely lost an opportunity of acting liberally.

Mr. ALEXANDER BREMNER was the eldest son of the late Mr. James Bremner, of Harbour Place, near Wick, N.B., a very old Member of the Institution, and of whom a memoir has already appeared.[1] After receiving a practical education on various works under his father, Mr. Alexander Bremner was engaged for about six years as Assistant-Engineer on the works at Lossiemouth, Carnish, and Calicott Harbours; he then acted as assistant to his brother, the late Mr. David Bremner[2] (M. Inst. C.E.), at the West Hartlepool Harbour Dock-works, under Mr. James Simpson (Past-President Inst. C.E.); and he next practised for six years on his own account as a Civil Engineer, during which time he was employed with his father in assisting in floating the 'Great Britain' in Dundrum Bay, which was recovered in 1847. He also executed several piers and harbour improvements at Rothsay, Gourock, Innellan, &c.; and made many plans and reports for engineering works.

In the early part of the year 1862, he proceeded to China on an enterprise connected with the raising of submerged vessels, when he was attacked with cholera, to which he succumbed after only eight hours' illness, at Shanghae, on or about the 20th of October, 1862.

Mr. Alexander Bremner had only joined the Institution of Civil Engineers as an Associate in the previous year; but from the

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xvi., p. 113.
[2] *Ibid.*, vol. xii., p. 148.

interest he evinced in the proceedings, it was evident that, had his life been prolonged, he would have followed the example so worthily set by his father, and would have contributed some useful practical experience to the stock of professional knowledge.

Mr. ALEXANDER BRODIE COCHRANE was born at Dudley, in the year 1813. After receiving a plain substantial education, he was placed at the ironworks of Messrs. Grazebrook, where he obtained a thorough knowledge not only of the business of a founder, but also of the manufacture of iron from the ore, as well as of the principles of mining, under his father, who had the entire management of Messrs. Grazebrook's colliery and furnaces. Afterwards, at a very early age, he became a partner of the late Mr. John Joseph Bramah, and commenced business as an iron-founder at Bilston. Subsequently they, in conjunction with Mr. Cochrane's father, founded the Woodside Ironworks and Foundry, which were carried on with much success until the decease of Mr. Bramah. Mr. Cochrane was then joined by the late Mr. Charles Geach (Assoc. Inst. C.E.) and the late Mr. A. Slate (Assoc. Inst. C.E.), the firm being carried on under the name of Cochrane and Co., by whom also the works belonging to the firm at Middlesborough, and known as the Ormesby Ironworks, were established. After the death of Mr. Geach, Mr. Slate left the firm, which had at that time attained a wide reputation, and was particularly known as having supplied most of the ironwork required for the Great Exhibition building of 1851. He was afterwards joined by his brother, Mr. John Cochrane (Assoc. Inst. C. E.), who devoted his attention more especially to the engineering branch of the establishment; since which time the firm has executed many large contracts, particularly some of the iron bridges over the Thames, recently completed. By his assiduity and skill he obtained for his firm a great reputation for the manufacture of cast-iron pipes, and they supplied nearly all the principal water and gas companies of the country, as well as many on the continent, and in the colonies. He was a magistrate of the counties of Worcester and Stafford, and obtained considerable influence in those counties.

Mr. A. B. Cochrane joined the Institution of Civil Engineers as an Associate in the year 1850, and remained connected with it until his death, which occurred on the 23rd of June, 1863, at the early age of 50 years.

Mr. WILLIAM COULTHARD, who was born in the year 1796, commenced his career as a practical mason, under his father, who was a Contractor.

In 1824 he was engaged by the late Mr. John Green to assist in the execution of some heavy works near Newcastle-on-Tyne, amongst which may be mentioned the Suspension Bridge over the river Tyne at Scotswood; the stone bridge over the river Tees, at Blackwell, near Darlington; the Free Schools at North Shields, and other public buildings.

In 1834 he rebuilt the stone bridge over the river Esk, at Whitby.

In 1835 he may be said to have commenced his railway career by undertaking the construction, under Mr. C. Vignoles (M. Inst. C.E.), of the North Union Railway, of which, on the completion of the line, he became the Resident Engineer, a position which he held for eleven years with great advantage to the Railway Company, and with so much credit to himself, that on quitting that post he was publicly presented, "by his fellow-servants and other friends," with a flattering testimonial, consisting of a silver tea and coffee service, as evidence of the high opinion they entertained of the strictness and impartiality of conduct with which Mr. Coulthard had carried out the duties of his office. On that occasion Mr. Vignoles, who occupied the chair, paid some well-merited compliments to the worthy recipient of this mark of the goodwill and proper appreciation of the fellow-officers of Mr. Coulthard, who, in reply, expressed his regret at quitting a position endeared to him by so many pleasant remembrances, even although he did leave with the intention of commencing the career of contractor for public works.

The first contract undertaken by him was the construction of the Little North Western lines, of Ingleton, Kirkby Lonsdale, and Clapham, and the Clapham and Lancaster. Next he executed the Morecambe Harbour and Pier, and then the Lune Valley Railway, under Messrs. Locke and Errington (M.M. Inst. C.E.). Subsequently he constructed the Morecambe and Hest Bank line, with other works, in which he had the assistance of his sons.

His career was successful and honourable, and his decease, which occurred in London on the 19th of March, 1863, was much regretted by a wide circle of friends.

He joined the Institution of Civil Engineers as an Associate on the 26th of June, 1849, and always evinced much interest in its advancement.

Mr. Alderman WILLIAM CUBITT, M.P., who was born in the year 1791, began life in the Royal Navy, but he soon abandoned the sea and joined his brother, the late Mr. Thomas Cubitt (Assoc. Inst. C.E.), as a builder, and for many years he carried on a very successful business in Gray's Inn Road, covering large tracts of

land, in the north-west of the metropolis, with fine houses, and also executing some extensive railway contracts, amassing a large fortune, which he used in a most praiseworthy manner.

At an early period he became interested in City affairs, and in 1847 he served the office of Sheriff of London and Middlesex. In the same year he was elected the representative in Parliament of the borough of Andover, of which place he continued to be the sitting Member until the period of his decease, with the exception of a short interval in 1861-62.

On the decease of Sir John Key, in 1851, he was elected Alderman of the Ward of Langbourne, and in 1861 he was elected Lord Mayor of the City of London, the duties of which post he performed with so much uprightness, intelligence, and hospitality, that he was re-elected for the year 1862. During this double tenure of office he commanded in an extraordinary degree the respect and confidence of the Court of Common Council and of the citizens generally, and he was enabled, by his munificent example, to raise larger sums of money, as contributions to public charities, than had ever been previously subscribed.

He took a very prominent part in originating the public subscription towards the erection of a memorial to the late Prince Consort, and was, by Her Majesty, nominated to serve upon the Committee for assisting in the decision of the form of the Memorial.

Mr. Cubitt was also President of St. Bartholomew's Hospital, Prime Warden of the Fishmongers' Company, and a magistrate for Middlesex and Surrey.

He was elected an Associate of the Institution of Civil Engineers January 22nd, 1833; served on the Council for the Session 1842-43; contributed, in 1840, an original communication to the Society, 'On a new mode of covering Roofs with Planking,' which was published in the Minutes of Proceedings,[1] and was a frequent attendant at the Meetings, taking much interest in the proceedings and welfare of the Society.

He was essentially the architect of his own fortune, rising to distinction and a very honourable position entirely by his own exertions. He was justly popular, and was highly esteemed for his good sense, probity, and suavity of manner, and his decease, which occurred on the 28th of October, 1863, at his seat, Panton Lodge, Andover, in his seventy-third year, was a source of deep regret to his family and to a large circle of attached friends.

MR. CHARLES MICHAEL JOPLING, second son of Mr. Joseph Jopling, Architect, was born in London on the 30th of March,

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. i. (1840), p. 68.

1820, and there he continued to reside until the age of fifteen, when he accompanied his father on a visit to examine and report on the slate-quarries of Wales, and those of Kirkby Ireleth, in the north of Lancashire, made at the request of the Earl of Burlington, now the Duke of Devonshire, who was desirous to increase the amount of slate obtained from his own quarries at Kirkby Ireleth, and at the same time to facilitate the transit to the shipping port. The improvements which were then suggested were afterwards carried out, under the direction of Mr. Joseph Jopling, who, in order to be near the works, removed from London to Furness Abbey, where he remained till 1843. During his residence in Furness, Charles Jopling was engaged in making studies with his elder brother for the then proposed tramway, or railway, from the slate-works to Barrow and Piel Harbours, in conjunction with a line to unite the iron-ore mines and other products of the district. About the same time it was proposed to enclose Morecambe Bay and the estuary of the Duddon, by constructing a railway from Lancaster to Whitehaven ; Capt. Sir H. Senhouse, R.N., taking an active part in the projected undertaking, and C. M. Jopling being employed, with others, in making studies, under the direction of Mr. Hague, C.E.

During his leisure hours, the young Engineer delighted in examining the many objects of interest surrounding his home, and the beautiful ruins of Furness Abbey were correctly measured, and drawings made of every part, some of which have found a place in a valuable work,—"Annales Furnesienses. History and Antiquities of the Abbey of Furness, by Thomas Alcock Beck, Esq.," published in 1844, for which he received the Author's thanks.

His interest in geology attracted the attention of the Earl of Burlington, who gave him the work by Sir Henry de la Bêche, as a present from Lady Burlington, encouraged him in his studies, and also contributed to his small work, called "Furness and Cartmel, for the use of Visitors," published in 1843.

On returning to London in 1843, he was for some time engaged under Mr. Simpson (Past President Inst. C.E.), and also under Mr. Lynde (M. Inst. C.E.), and at a later period he was with Messrs. Stephenson, Brassey, and Mackenzie, during the construction of the railway from Kendal to Windermere. From that place he moved to the works in the neighbourhood of Carlisle, and afterwards to Scotland, as far as Inverness, travelling over many projected lines of railway in England ; his geological knowledge giving him great facility in ascertaining the nature of the work required in the proposed lines.

In 1844, a letter written by him to Mr. George Godwin, F.R.S., on the remains ascribed to the era of the Druids in Furness, was

communicated to the Society of Antiquaries,[1] and was afterwards published in the "Archæologia, or Vetusta Monumenta."

In connection with Mr. Fell he contracted for the construction of part of the railway between Ulverston and Dalton and Broughton in Furness, and at a subsequent period he undertook the Dutton Viaduct, together with some miles of railway on towards Whitehaven, to connect the Furness with the West Cumberland Railways. In this his elder brother joined him, and remained in connection with him up to the time of his decease. Upon the completion of these works in 1851, he went to Italy to examine the route of a proposed railway from Rome to Ancona. The first work upon which he was actually engaged in Italy was the railway from Genoa to Voltri, which will form part of the main line along the coast of the Mediterranean, from Marseilles to Civita Vecchia. After leaving Genoa, he went to reside in Florence, and took an active part in the commencement and construction of the railways from Piacenza to Bologna, and thence to Florence, as partner in the firm of Messrs. Jackson, Brassey, Fell, and Jopling, contractors. On the breaking out of the Italian wars, he brought his family to England, but returned himself to Italy; and during that period he was much in Tuscany, superintending the completion of the line between Pistoja and Lucca, in consequence of the death of his younger brother, who had charge of it. About this period he employed a competent scholar to make a transcript from the marginal notes of Savonarola, in the Magliabecchi Library at Florence. After the peace, a concession was granted for a railway from Leghorn to the boundary of the Papal States, near Civita Vecchia, called the "Maremma Railway." The contract was given to Messrs. Brassey and Co.; Messrs. C. M. Jopling and C. Jones acting as the principal agents. The first sod was cut at Leghorn by Baron Ricasoli, on the 28th day of February, 1861, and nearly 100 miles of the line were made in less than two years; the contractors executing all the working drawings, subject to the approval of the Government Engineers—at one time upwards of ten thousand men were employed upon the works.

Towards the close of 1862, Mr. Jopling's health began rapidly to fail; the principal cause of its decline being repeated attacks of malaria fever, which he had caught some years previously in the vicinity of Rome, and from the effects of which he eventually died at Leghorn on the 20th February, 1863. His affable and pleasing manners, united with an extremely amiable and generous character, had gained him the affection of all who knew him. He was buried in the Protestant cemetery at Florence, by the side of his

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[1] *Vide* "Transactions of the Society of Antiquaries of London," vol. xxxi., p. 448.

younger brother, Samuel, who had been laid there only a few years previously.

Mr. Charles M. Jopling was elected an Associate of the Institution of Civil Engineers on the 11th of March, 1845; and whenever the opportunity presented itself, he never failed to attend the Meetings, and to take advantage of the other facilities offered by the Institution.

Mr. APSLEY PELLATT, the eldest son of Mr. Apsley Pellatt, a glass manufacturer, was born in the year 1791. Brought up to his father's business, he, by great assiduity and attention, especially to the artistic improvement of glass-ware, and by enterprising industry, caused the firm, of which he eventually became the principal, to attain a very high position in that particular branch of manufacture. It is said that the manufacture of crackle glass, for which Venice was so celebrated, and the art of making which was kept secret, was rediscovered by Mr. Apsley Pellatt, in 1851, and that to him also is due the merit of the invention of the method of ornamenting glass with delicate white Argentine incrustations of dry porcelain clay, cemented into the solid glass. It is also stated that when the Astronomical Society of London appointed a Committee for the purpose of making experiments on the manufacture of optical flint-glass, Mr. Pellatt liberally placed at the service of the Committee the resources of his glass-house, and his own large experience.

Many years ago, Mr. Pellatt published a memoir, "On the Origin, Progress, and Improvement of Glass Manufacture," which was soon out of print, and having subsequently delivered lectures at the Royal Institution, "On the Manufacture of Flint Glass, and the Curiosities of Glass Making," he embodied the materials so collected, illustrating the history of the invention, in a little work on "Curiosities of Glass Making; with details of the Processes and Productions of Ancient and Modern Ornamental Glass Manufacture," (4to. coloured plates and cuts. London, 1849); and at the International Exhibition of 1862, he was a Juror in Class xxxiv., and drew up the Jurors' Report upon stained glass and glass for decoration, as well as upon glass for household use and fancy purposes.

Mr. Pellatt was elected an Associate of the Institution of Civil Engineers on the 13th of February, 1838; he served on the Council for the Session 1840, and was an Auditor of accounts during the years 1845 and 1846. He presented two original communications to the Institution, one, "On the relative Heating Powers of Coal and Coke in Melting Glass;"[1] the other, "On the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. i. (1838), p. 39.

Manufacture of Flint Glass,"[1] and he was for many years a constant attendant at the Meetings, frequently joining in the discussions—the last occasion being in the year 1853, in the course of a debate on the drainage of the district south of the Thames; when he said, as an old inhabitant of that part of the metropolis, he was well acquainted with the state of its sewerage, and, as one of the representatives in Parliament of the Borough of Southwark, he was deeply interested in the proposed steps for ameliorating the condition of the valuable properties situated there.

His influential position in the Borough of Southwark, where he so long resided, brought him into prominence as a politician. When Mr. Miall contested that borough with Sir W. Molesworth in 1845, Mr. Pellatt was one of his most zealous supporters, urging the claims of the anti-endowment candidate upon the electors. At the general election in 1852, Mr. Pellatt was himself returned by that constituency, in conjunction with Sir William Molesworth, and he remained a useful member of the legislature for five years, interesting himself in various commercial questions, and voting in favour of all measures of reform. During the last twenty years of his life, Mr. Pellatt resided at Staines, in Middlesex. He took a leading part in the movements of the congregational body, contributed liberally, both of his time and money, to chapel extension, and was always ready to lend a helping hand to every good cause, whether in behalf of religion, education, or philanthropy. Mr. Pellatt died of paralysis on the 17th of April, 1863, after an illness of little more than a week's duration, in the seventy-second year of his age.

Mr. CHARLES WILLIAM SCOTT, youngest son of the late Mr. John Scott, of Sunderland, was born on the 12th of January, 1831. He was educated at Sunderland, Edinburgh, and Brussels, and at an early age was articled to Mr. Thomas Meik, the Engineer to the Commissioners of the River Wear, and was subsequently engaged for several years under Mr. John Murray (M. Inst. C.E.), whilst the docks at Sunderland were being constructed, thus obtaining considerable knowledge and experience in sea-works, which eventually proved to be so useful to him. He was then for three years employed on the survey, and during the formation of the Grand Trunk Railway, of Canada. On his return from that country, he accepted an appointment under Mr. Alexander Gordon (M. Inst. C.E.), and for three years had charge of the erection of two important lighthouses in the Bahamas, at

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. i. (1840), p. 37.

Lobos Cay and at Great Isaacs, and surveyed and reported on several other sites in the same locality. He was always particularly careful of the supplies for, and the health of, the working parties, precautions most essential in such a hot climate, and even though the site of the operations might be from 100 miles to 200 miles distant from whence supplies could be obtained, he managed to keep the men satisfied and well in hand—no easy matter considering that they had generally been bred and brought up as wreckers, pirates, or even worse. On the completion of these works, he returned to England, and after a residence at home of only a few months, he was selected by Mr. W. Parkes (M. Inst. C.E.) to complete the erection of three lighthouses in the Red Sea. It was while in this service that he contracted dysentery, which speedily terminated his career, though he lived to come home to die; his decease occurring on the 11th of January, 1863, before completing his 32nd year. With regard to his conduct of this particular work, Mr. Parkes has stated, that he considered himself under great obligations to Mr. Scott for the manner in which he devoted himself so nobly, and with so much success, to the performance of the duties intrusted to him.

Mr. Scott was devoted to his profession, and had abilities of a high order. He had the faculty of obtaining and retaining the respect and regard of those under whom he served, and amongst his relatives and friends he was universally esteemed for his quiet and unobtrusive manners, from which, aided by his industry and great perseverance, they had looked forward to his taking a high position in the profession he was so ardently attached to.

Mr. Scott only joined the Institution of Civil Engineers as an Associate in January 1861, just previous to his departure for the Red Sea, so that he was not able to take part in the proceedings, as, had he been spared, he might have been expected to do.

Rear-Admiral JOHN WASHINGTON, C.B., F.R.S., &c., was born on the 1st of January, 1801, and entered the Royal Navy in 1812, on board the 'Juno,' fitting for the American Station, where, as well as afterwards on board the 'Sibyl,' he saw some active service, and profited by the scientific instruction of the then Master of the vessel, afterwards Sir W. Bain, under whom he attained great proficiency in making astronomical and magnetical observations.

After a cruise of two years' duration, on his return to England he continued his studies, for two years, at the Royal Naval College, Portsmouth, where, in 1816, he gained a prize gold medal, and laid the foundation of the skill and accomplishment which he

afterwards attained in nautical surveying and hydrography, and through which, in his subsequent career, he was enabled to render so much valuable service to the maritime interests of this and other countries.

He then served for three years on board the 'Forth,' on the North American Station and in the Pacific. On receiving his promotion as Lieutenant, in 1821, he obtained leave of absence, landed at Valparaiso, crossed the Andes to Mendoza, and rode over the Pampas to Buenos Ayres, taking advantage of the opportunity to make some useful observations.

Soon after his return to England he was transferred to the 'Parthian,' and was sent to the West Indies, where, his health failing, he obtained leave and travelled in France, Spain and Italy, acquiring facility in speaking the languages of these countries.

In 1827, he was again afloat, and for four years, on board of the 'Weasel' and the 'Dartmouth,' he was stationed in the Mediterranean, when he found time to explore the interior of Morocco in company with the English Consul-General Drummond Hay, making astronomical observations and fixing the true position of places hitherto undetermined. A memoir containing these observations was communicated to the Royal Geographical Society, and was published in the first volume of the Journal of that Society.[1]

Attaining the rank of Commander in 1833, he remained for some time ashore, prosecuting his scientific studies and rendering valuable assistance to the then young Geographical Society, to the position of Secretary of which he was elected in 1836. To the vigour infused by him into the proceedings, in stimulating important expeditions, counselling and aiding travellers, and improving the publications, to the editing of which he devoted himself assiduously, may be, in a great degree, attributed the first success of the Geographical Society. He also advocated the practice of annually reviewing the progress of geography during the past year, which was adopted by Mr. W. R. Hamilton, in 1839, and has been continued since the period of his Presidency, setting an example to many of the older societies.

After the devotion of five years of valuable time to the Society, he, in 1841, was again afloat in the 'Black Eagle,' in which ship he brought the late King of Prussia to England;—his promotion to the rank of Post Captain is said to have been influenced by the impression made upon the mind of Baron Alexander Von Humboldt, by the varied acquirements and knowledge possessed by Commander Washington.

He was then intrusted with the command of the 'Blazer,' and

[1] *Vide* "The Journal of the Royal Geographical Society of London," vol. i p. 123. London. 1833.

was employed in nautical surveying until 1847, and in 1855 he succeeded the late Admiral Beaufort as Hydrographer of the Admiralty, a post for which he was thoroughly fitted by his knowledge of the subject, his habits of business, and the spirit of order and regularity which he so well knew how to infuse into all who served under him. He had now full scope for affording aid to all explorations; and, with his religious views, it is not surprising that he should especially aid and counsel Dr. Livingstone in his enterprises. He also was conspicuous in aiding Lady Franklin in her efforts to obtain information as to the fate of her long-lost husband.

In due course he became an Admiral, and, in his official position at the Admiralty, Washington was very frequently in contact, and sometimes in official collision, with Civil Engineers, but in all cases his urbanity, plain sailing, and honesty of purpose, converted contests into friendly meetings; and he will long be remembered with regret by the majority of Civil Engineers.

Exhausted by overwork, he obtained leave of absence to travel on the Continent, where for a time he appeared to revive; but a relapse occurred, and he sank and expired at Havre-de-Grace, September 16th, 1863, in his sixty-third year. On the occasion of his funeral well-deserved honours were paid to his memory by the scientific men of France and the authorities of Havre; and a very interesting memoir was published by Monsieur D'Avezac.

Admiral Washington was a Fellow of the Royal Society and a member of several other of the scientific societies of the metropolis.

He joined the Institution of Civil Engineers as an Associate, March 11th, 1845, was a frequent attendant at the meetings, taking part in the discussions, and he was ever ready to afford assistance to the Society by lending or giving charts, or in any other way concurring in the objects of the Institution. He was an unaffectedly pious, worthy man, a highly educated conscientious officer, and whether in public or private, he set a good example to all around him.

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